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A COMPARISON OF TWO SYSTEMS OF ANESTHESIA FOR THORACIC SURGERY

ETHER VERSUS THIOPENTAL-SUCCINYLCHOLINE

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IN COMPARING any two systems of anesthesia, it will be profitable to keep in mind the effectiveness of each in permitting the anesthetist to overcome the chief problems of the type of surgery involved. In thoracic work the principal hazards to be overcome by the anesthesia system or by the anesthetist are as follows: obstructing secretions, troublesome vagal reflexes of the respiratory and circulatory systems, anoxia, elevation of carbon dioxide tension, circulatory strain, motion within the thorax, and finally the hazard of explosion.

At the present time I should like to compare (a) ether anesthesia, as carried out traditionally for many years for thoracic surgery, and (b) thiopental sodium-succinylcholine chloride anesthesia (Pentothal-Anectine). For a considerable period we have been using the thiopental-succinylcholine sequence at the rate of about 4,000 cases per year for all types of major surgery, including the longest and most complicated thoracic procedures, in order to get firsthand insight into its advantages and limitations. We believe that this agent has, because of its greater controllability, considerable superiority over the various forms of curare utilized for much the same purpose over the past decade and a half. Now to consider the principal hazards.

Obstructing Secretions.—Both ether and succinylcholine produce in many subjects a rather heavy flow of saliva and mucus. This is objectionable but

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not difficult to handle with either system of anesthesia, inasmuch as these secretions can be easily aspirated through the universally employed endotracheal tube. In sudden emergencies of obstruction of the airway, as from profuse secretions or blood, the muscle relaxant system permits swifter control of the situation.

Troublesome Vagal Reflexes of the Respiratory and Circulatory Systems.—Cough, of course, normally depends on local irritation in air passages and it can be initiated elsewhere by stimulation of afferent vagal fibers. The reflex arc is completed by motor nerves which carry efferent impulses to the intrinsic and accessory muscles of respiration. Effective cough requires a closed chest wall, but cough can still spread the contents of the lungs and bronchial tree even though its effectiveness be somewhat aborted by the open chest. A considerable depth of anesthesia is sometimes required to obliterate cough under ether. The muscle relaxants appear to be superior and succinylcholine can be used to control cough absolutely and with only a light level of anesthesia. Cough, in conjunction with light ether anesthesia, may be particularly dangerous during certain stages of intrathoracic procedures. In the patient in poor condition, the considerable depth of ether anesthesia required to abolish cough may seriously depress the patient's blood pressure. Succinylcholine, with its transient action and easily varied depth of muscular paralysis, is better than ether for control of cough.

Anoxia.—With properly managed anesthesia, anoxia is rarely a serious hazard in thoracic surgery any more. In earlier days, patients with profuse purulent secretions in the airway were a commonplace. It was sometimes difficult to maintain in them a satisfactory airway and adequate oxygenation, but with the advent of chemotherapeutic agents this problem has been largely overcome. One anesthesia regime is as good as the other in the majority of cases as far as oxygen supply goes, except in cases of obstruction of the airway when swift intubation and aspiration are essential. In this case, the muscle relaxant sequence is the better, as mentioned. This system is also probably better when severe emphysema is present, used with a ventilator which provides for the use of negative as well as positive pressure.

Elevation of the Carbon Dioxide Tension.—A far greater and more common problem in thoracic surgery than that of anoxia is that of an elevated tissue carbon dioxide tension, as Miss Murphy and I first showed with factual data (Beecher and Murphy,[1] 1950) and as many others have since confirmed. With ether anesthesia (Beecher, Quinn, Bunker, and D'Alessandro,[2] 1951) in the most difficult situation, namely, that of pneumonectomy, we were never able with the "educated hand" squeezing the bag to get the carbon dioxide tension to normal levels, although this was quite easy in the lobectomy group.

The last time Dr. Gibbon and I discussed this question, comparing, in pneumonectomy cases, machine methods with our manual ones, I thought we still had a little the better of the argument[2] inasmuch as pneumonectomies on the machine showed 74 mm. of mercury carbon dioxide tension and ours by hand 58 mm. of mercury tension. Since that time, however, ventilators have been improved and we have been particularly well pleased with the Jefferson

ventilator, which makes possible the simple use of varying degrees of positive or negative pressure. Unless the anesthetist has sticky fingers, it is not possible for manual ventilation to produce negative pressure in the airway. We have not yet got around to running a series of carbon dioxide tensions in patients undergoing pneumonectomy and on the ventilator, but there is no doubt in my mind that one could easily maintain carbon dioxide tension at a normal level with this improved ventilator in conjunction with the use of muscle relaxants. We hope to obtain factual data on this score; perhaps others have already done so. It is possible to use the ventilating machine with ether. It is my impression that this is sometimes more difficult with ether than with succinylcholine.

Undoubtedly it is desirable for the anesthetist to get from time to time the "feel of the bag" by manual use. By so doing he can appraise the ease or difficulty of inflation of the lungs. Properly designed ventilators make the shift to hand use possible without difficulty.

Circulatory Strain.—The strain on the circulation produced during open thoracic procedures is undoubtedly great, judging by the response of patients to such procedures. It has long been our contention that the crippled cardiovascular system of elderly individuals stands ether anesthesia very well indeed. There is much evidence to support this. We have never supposed, however, that ether was perfect in this regard. It will be very important to run a carefully controlled series of alternate cases with the two systems in order to settle the matter of which produces the greater strain on the circulatory system. I do not know the answer to this, nor do I believe anyone else does as yet. I can only say at the present time that we have been very well pleased with our experience using the thiopental-succinylcholine technique for prolonged and difficult transthoracic procedures such as esophagectomy, transthoracic gastrectomy, and so on.

We have long believed that it was important to alternate cases and to try to study in a factual way these two systems of anesthesia. So far we have had very great difficulty in convincing anyone else of the importance of this to the extent of getting financial support for such a study. I do not believe it is possible, within a reasonable period of time, to arrive at the correct answer to this question without such a comparative study. While a good many people raised a considerable protest over our death rate study (Beecher and Todd,[3] 1954), where we showed among other things that the deaths during *induction* of anesthesia were more than five times higher when muscle relaxants were used than when they were not, no one has yet obtained evidence contradicting those findings. It should, of course, be kept in mind that those observations were based largely on curare-type agents, not on the newer succinylcholine. There is need for a careful comparison of the two systems of anesthesia discussed here. One's conclusions must not be hastily arrived at. I should like to point out that to cast up even a rough appraisal of death rate most statisticians require no fewer than ten deaths. Suppose for a moment that the death rate from anesthesia is at the appalling level of 1:100 cases, it will still take 1,000 cases to demonstrate that fact even approximately. For

this and other reasons, an adequate comparison will be a tedious, time-consuming, and expensive proposition. The alternate cases procedure urgently needs to be carried out.

Answers to many questions are wanted in this connection. We need to have more information than we have as to what the comparative effects of the two systems of anesthesia may be on the circulating blood volume. There is some evidence of peripheral stagnation, for example, in the tendency of the fingers and toes to be quite cyanotic under the thiopental-succinylcholine regime as compared with ether, while the blood in the thorax or abdomen is properly oxygenated. One needs to know how extensive and significant the rather obvious stagnation may be under the thiopental-succinylcholine system. This cannot be settled in an easy chair. The extent of this disability can be determined only by painstaking studies. There are plenty of unsolved problems here which can be settled by the comparative type of study just mentioned.

Motion within the Thorax.—While surgeons vary greatly as to how much motion within the thorax they will tolerate, unquestionably quietness is always an advantage and an urgent necessity at some phases of most intrathoracic procedures. The muscle relaxant system provides this more dependably than does ether.

The Hazard of Explosion.—I have always considered myself lucky that the surgeons at the Massachusetts General Hospital consider the use of the cautery or diathermy as contraindicated for surgical reasons. They do not use it in the chest. In the hospitals where such use is the custom, or desired, a nonexplosive procedure is necessary. In addition, there is the small but definite hazard of explosion of ether for unknown reasons. The thiopental-succinylcholine sequence solves this problem; ether does not.

Miscellaneous Points.—Thiopental was long ago discredited in the bled-out patient, the patient in shock, the patient with myocardial disease, the patient with severe asthma. We need to know whether the thiopental-succinylcholine system is as safe as ether for such cases. The proposed alternated case study would eventually give sound answers to these questions. I have had some difficulty in a case or two with the ventilator in very obese patients. Finally, I think there is no question as to what the results will be if untrained anesthetists, if war comes, suddenly begin to use the muscle relaxants in severely wounded or even scarcely wounded men. Thiopental alone, in North Africa in 1942 and 1943, was a fearful agent of death. The problem will be greatly compounded by the muscle relaxants in the hands of inexperienced anesthetists. One can hope that those charged with military policy planning are giving this problem the attention it deserves.

SUMMARY

The hazards in thoracic surgery which concern the anesthetist have been considered in terms of whether they are best overcome by ether anesthesia or by thiopental-succinylcholine. After a considerable use of the latter system for prolonged and difficult operations for thoracic surgery the following points emerge.

Obstructing secretions: These can be handled equally well under the two systems in ordinary cases. When profuse purulent secretions or blood obstruct the airway and constitute a sudden emergency, the muscle relaxant sequence is better.

Troublesome vagal reflexes in the respiratory and circulatory systems: Cough and other troublesome variations of respiratory force and rate can be best controlled by the muscle relaxant sequence.

Anoxia: Anoxia should be easily prevented with either system of anesthesia. In acute emergencies, as when serious bleeding occurs or when the airway becomes obstructed, speed of intubation and aspiration may be important. This can be more quickly and efficiently taken care of with the muscle relaxant sequence.

Elevation of carbon dioxide tension: There seems to be little doubt that ventilator systems have now been developed to the point where they are more effective than the manual bag squeezing system in maintaining adequate ventilation. It is my impression that ventilators work better with the muscle relaxants than when ether is used.

Circulatory strain: It will take a good deal more experience than anyone has had to the present time to settle the question of which system is better tolerated by the circulatory system during open thoracic anesthesia. There are reasons to believe that the extensive use of thiopental with the muscle relaxant may constitute a considerable hazard. Certainly past experience has indicated that thiopental is exceedingly poorly tolerated by bled-out individuals or by those with crippled cardiovascular systems. The tendency to peripheral stagnation of blood with the thiopental-succinylcholine sequence may or may not be important. It is impossible to say at the present time how significant this may be. The matter needs study.

Motion within the thorax: Muscle relaxants undoubtedly permit more dependable control of this than ether does.

Hazard of explosion: There is no hazard of explosion when the thiopental-muscle relaxant sequence is used.

CONCLUSION

It can be seen from the above comments that the thiopental-succinylcholine sequence provides a better solution to all problems encountered, with the exception, that a crucial question still remains as to how morbidity and mortality of the two systems will compare. A far wider experience will be required to settle these matters than as yet has been possible for anyone. There is a great need for a systematic alternation of cases in large numbers to settle this important matter.

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(For Discussion, see page 474.)

A CONSIDERATION OF PROPER METHODS IN THORACIC ANESTHESIA

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IN RECENT years, interest and study in thoracic surgery have been concerned with the important physiologic disturbances associated with intrapleural operation and with the development of many improvements in surgical technique including the development of vessel prostheses. Vital as these interests are, they have unwittingly shifted the focus of clinical concern away from the relatively simple practical problems that often make for success or failure in the anesthetic or surgical management of the thoracic surgical patient. It is the purpose of this paper to review and remind surgeons and anesthesiologists of the physiologic and clinical abnormalities which may occur during some essential and simple anesthetic procedures. Obviously no relationship between these changes and mortality or even morbidity can be assessed with certainty. However, it is suggested that serious disturbances of ventilation or circulation may be the consequence of even subtle difficulties with procedures as simple and as common as laryngoscopy and endotracheal intubation.

ENDOTRACHEAL INTUBATION AND ITS EFFECTS

It is hardly necessary to remind thoracic surgeons that any of the premedicant sedatives, any anesthetic agent, and the skeletal muscle relaxant drugs may cause hypoventilation. It is also well known that the consequences of hypoventilation are anoxia and respiratory acidosis. However, it has not always been appreciated either in clinical care or in scientific study that apparently minor events, frequently unrecognized, may also contribute to the development of hypoventilation. Endotracheal intubation is a commonplace occurrence in thoracic surgery but the possible relationship to "malventilation" has not been sufficiently heeded. Disturbed breathing may begin with laryngoscopy. There are very few data which indicate the effect on gas exchange of the time required to perform laryngoscopy and endotracheal intubation. In at least one study[1] showing little change of blood pressure on direct recording during laryngoscopy and intubation of approximately 30 seconds, it was believed that this procedure caused no serious harm to the circulation or gas exchange. It

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is fairly common, however, to intubate leisurely without making a deliberate effort to reduce the time between effective breaths consumed by the procedures of laryngoscopy, intubation, and restoration of effective ventilation.

If the patient has been ventilated with a high concentration of oxygen, anoxia does no develop. However, the longer that ineffective ventilatory movements exist, the greater the probability of retention of carbon dioxide. Measurements in our laboratories showed an increasing acidosis in the induction or "para-intubation" period[2] (Fig. 1). Frequent observations at 2 to 3 minute intervals were necessary to ascertain this pattern of development of acidosis and were made possible by Holaday's modification of the glass electrode.[3] There were few instances in which acidosis did not occur whether breathing was spontaneous, assisted, or controlled in the "para-intubation" period. This complication can usually be prevented if the time between effective breaths is shortened to 30 seconds or less.

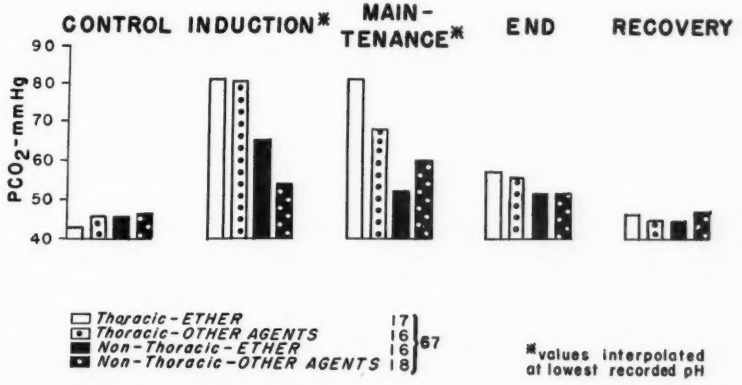

Fig. 1.—Summary of pCO_2 in arterial blood at various times during anesthesia and operation. Induction period extends from beginning of anesthesia and ends after endotracheal intubation. Respiratory acidosis is associated with the hypoventilation of deepening anesthesia and undue prolongation of the time between effective breaths.

Although speed is not a desirable goal in itself, it appears reasonable that the time between breaths should be no longer than 30 seconds in the hands of the average skilled anesthesiologist.

The implications of retention of carbon dioxide during the laryngoscopy and intubation period are the same as at any other time. This period of acidosis may produce electrocardiographic changes and potentiate vagal reflexes, quite important in view of the fact that an endotracheal tube is to be inserted immediately.

Another by-product of the appreciation that endotracheal intubation should be accomplished with skillful dispatch was the demonstration that technical difficulties and errors may effect undesirable circulatory consequences. In Fig. 2 the tracings of the left brachial artery and left femoral artery were made during laryngoscopy and intubation. At the first intubation, the irregularity in arterial pulses is quite obvious. This is the result of inadequate relaxation for intubation. The second intubation shows an uncomplicated and

unaffected circulation. Another interesting result of the manipulation of the endotracheal tube is shown in Fig. 3. It is believed and taught by most people that endotracheal tubes should be suctioned frequently and routinely during intrapleural operation. This procedure is obviously wise and necessary if there

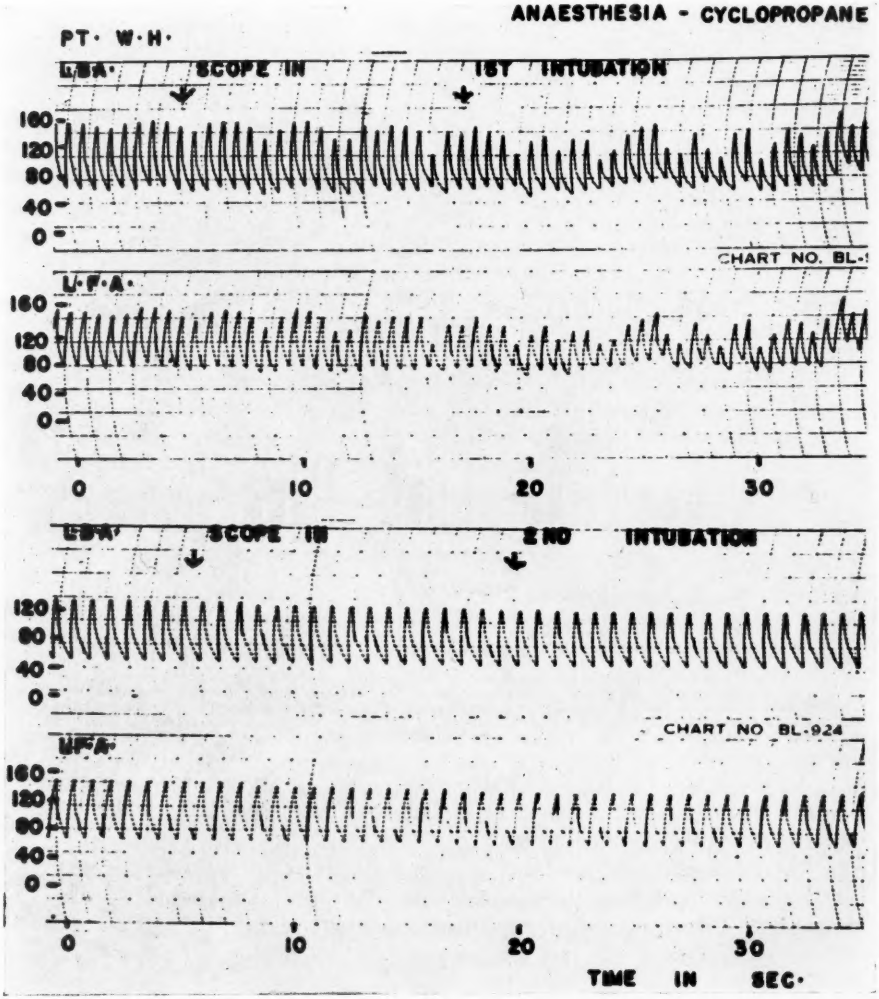

Fig. 2.—Lilly Capacitance Manometers and Brush Recorder used. Time interval marked in seconds. Tracings (upper) of left brachial artery and (lower) left femoral artery. Irregularity of pulse pressure noted during first intubation when relaxation was inadequate. Second intubation during adequate relaxation is without consequences.

is blood or secretion in the airway. It is not a reasonable maneuver if there is nothing available to suck and particularly if one realizes that endotracheal suction may cause harm to the circulation.

Occasionally an endotracheal tube is inserted too deeply. Fig. 4 shows the correction of the circulatory disturbance when the tube is withdrawn from the region below the carina. It must be emphasized that this circulatory disability might not have been detected by ordinary auscultatory measurement of the blood pressure. It is most important to examine the chest thoroughly after intubation to make certain that the tube was placed correctly.

Burstein and his collaborators showed that electrocardiographic changes following endotracheal intubation consist in general in increases in rate and a variety of arrhythmias, the most common of which is sinus tachycardia. They

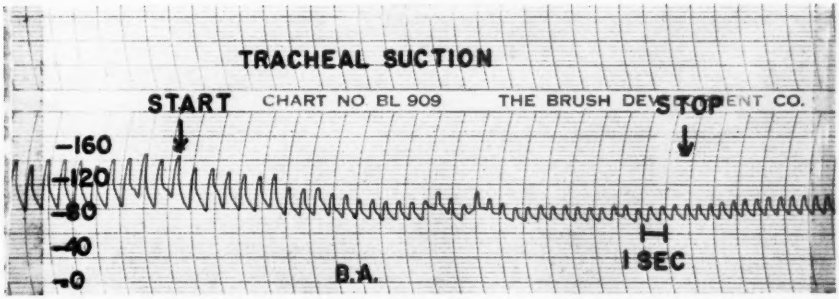

Fig. 3.—Marked diminution in blood pressure during endotracheal suction.

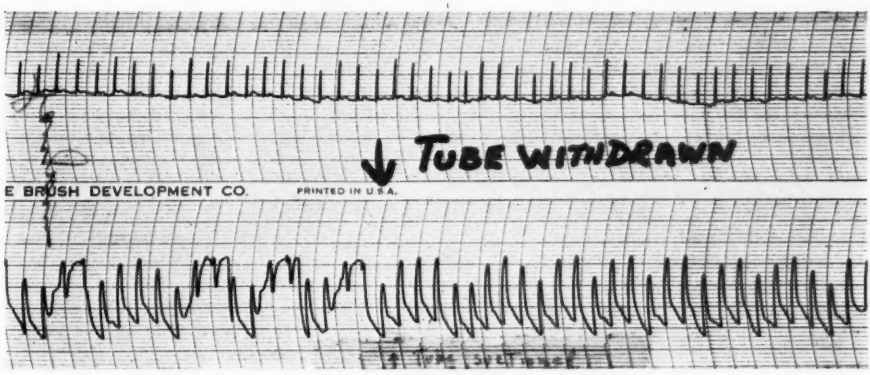

Fig. 4.—Correction of irregularity of pulse contour by withdrawing an endotracheal tube into the upper trachea.

concluded from these observations that circulatory changes incident to the manipulation of the airways were frequent, occurred in the majority of patients, and were due to increases in sympathetic rather than vagal tone.[4, 5]

King and his associates extended these observations and disputed some aspects of them in further studies.[1] They showed that intubation of the trachea uniformly produced an increase in blood pressure and an increase in heart rate. As anesthesia was deepened, these changes were less important. The circulatory changes did not appear to be related to any specific agent but were minimized with increasing depth of anesthesia.

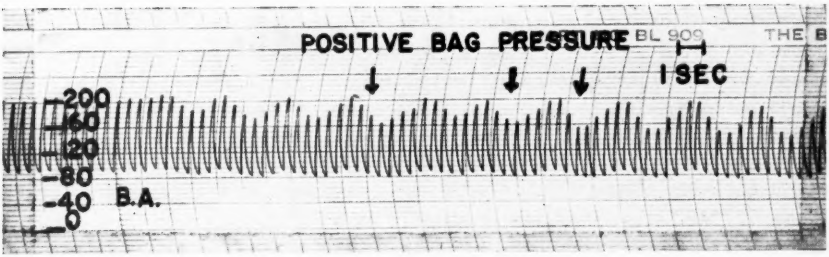

Fig. 5.—Depression of systolic blood pressure during positive pressure respiration by manual compression of the breathing bag.

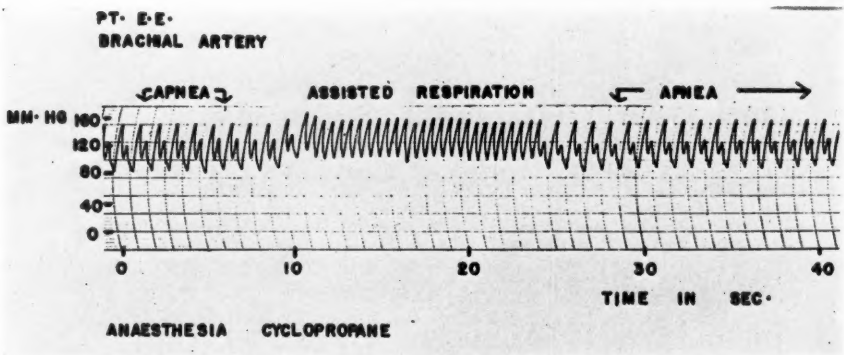

Fig. 6.—Irregular pulse and inadequate blood pressure during apnea, corrected by assisted respiration.

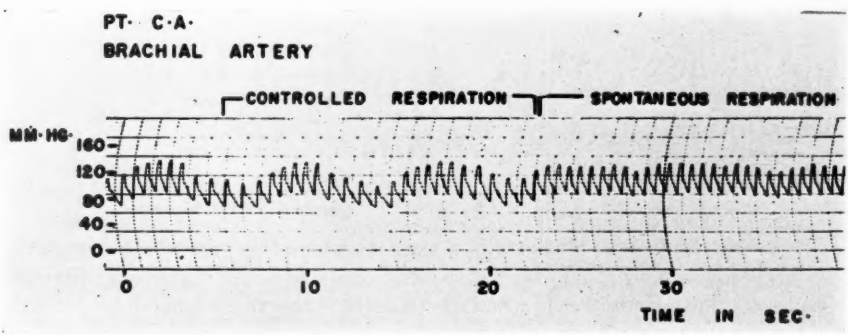

Fig. 7.—Rhythmic depression of blood pressure during positive pressure by manual methods, improved by the return to spontaneous breathing. The chest was closed when this observation was made.

In the patient with severe heart disease, one of the anesthetic goals is the use of light anesthesia. Tolerance to endotracheal manipulations of patients with diminished myocardial reserve during general anesthesia has been an important problem. Sometimes there is a dilemma. A patient with severely weakened myocardium may not tolerate anesthesia of depth sufficient to intubate. He may also respond unfavorably to the effects of intubation in light anesthesia even though topical anesthetics are instilled or nebulized into the airway. He may not do well with muscle relaxants. To solve this problem in patients with serious cardiac disability, it has been our practice to intubate in the conscious state with surface anesthetics. This statement does not infer that other methods are less satisfactory in other people's hands. It has been our experience that intubation prior to the establishment of general anesthesia has been a safe and useful procedure for patients with advanced heart disease.

THE EFFECTS OF ASSISTED AND CONTROLLED BREATHING ON THE CIRCULATION

Precise studies of the effects of positive pressure breathing will be presented by others in this symposium. However, it will be useful to describe a few instances of the circulatory effects of clinically conducted assistance or controlled breathing.

Fig. 5 shows the depression of systolic blood pressure which can occur from modest positive pressure applied to assist spontaneous breathing.

Fig. 6 shows the superiority of assisted breathing to apnea. It is shown to emphasize the need for unremitting assistance to breathing. The rhythm may be broken frequently when manual methods are used to adjust the transfusion, change the light, or record observations on the anesthesia record. These are practical reasons why efforts must be made to achieve physiologically sound mechanical ventilation.

Fig. 7 shows the superiority of spontaneous breathing to controlled breathing when controlled breathing is excessively applied. The chest was closed during this study.

CONCLUSION

Perhaps undue emphasis has been placed on the smaller events of laryngoscopy and endotracheal intubation during thoracic surgery. However, justification for this emphasis exists because it is tacitly assumed in scientific studies or clinical reports in thoracic surgery that there are no potential harmful consequences of intubation. This survey has made it obvious that such an assumption can never be made with security. This discussion will serve its purpose best if endotracheal intubation is performed to provide a minimum lapse between effective breaths and if subsequent anesthesia is conducted in the same manner.

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(For Discussion, see page 474.)

THE CARDIORESPIRATORY DYNAMICS OF CONTROLLED RESPIRATION IN THE OPEN AND CLOSED CHEST

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INTRODUCTION

FACTORS AND MECHANISMS INVOLVED

THE use of rhythmic inflation and deflation of the lungs for resuscitation or controlled respiration during surgery has become well established during the past several decades. Clinical and experimental studies have been performed to delineate the principles and practice of pressure breathing; and many mechanical devices have been developed to provide resuscitation, controlled respiration, and respiratory assistance.

However, divergent opinions persist, and it appears important to crystallize the issues by carefully evaluating the basic factors and mechanisms involved in pressure breathing. This would be especially useful if it established the over-all characteristics of a "physiologically ideal" respiratory pattern for both the open chest and the closed chest situation.

Factors Involved.—In order to be complete and adequate, such a study must include:

1. Determination of the characteristics of the normal respiratory pattern.
2. Analysis of *all* characteristics of the mechanical respiratory pattern by means of completely controlled experimental and clinical studies. These characteristics are: (a) position of breathing curve—(1) IPP, intermittent positive pressure, (2) PNP, positive-negative pressure, (3) INP, intermittent negative pressure; (b) amplitude of the pressure; (c) ratio of inspiratory:expiratory duration; (d) shape of the curve; and (e) rate per minute.
3. Simultaneous evaluation of both the ventilatory and the circulatory dynamics resulting from mechanical respiration.
4. Use of clinically applicable criteria for evaluating all of these factors.

The series of studies reported here was designed to comply with all of these requirements.

Measurements Involved.—The purpose of mechanical respiration is to produce optimal ventilation during surgery or resuscitation, without detriment to the

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circulatory system. The actual performance characteristics of the machines are important only as reflected in their physiologic effects on ventilation and circulation.

Optimal ventilation requires both adequate oxygenation of the blood and elimination of carbon dioxide. Accordingly, the ventilatory criteria we have used throughout these studies are the oxygen saturation and carbon dioxide tension (pCO_2) of arterial blood.

The effects of ventilation on the circulatory system can be measured in many ways. Determination of cardiac output or direct recording of arterial blood pressure provide the best over-all information and are used most often. Direct arterial blood pressure has been used here for several reasons: (1) previous studies have indicated that changes in right ventricular output resulting from pressure breathing are ultimately reflected in left ventricular output and arterial pressure; (2) direct arterial pressure provides a means for continuously monitoring over-all circulatory effects; (3) by means of a direct writer, it is possible to get instantaneous pressure readings; (4) the circulatory effects can be monitored on a beat-to-beat basis; (5) direct arterial pressure is more practical and easily obtained in a controlled series of tests where multiple readings are required over a long period of time, especially in patients undergoing thoracic surgery; and (6) arterial pressure, as a measure of circulatory effects, is used clinically during surgery or resuscitation, and results obtained in such controlled studies can be easily and directly applied to clinical situations.

In all of these studies, both experimental and clinical, blood pressure has been monitored continuously and recorded from a cannula in the femoral artery. Arterial oxygen saturation, pCO_2 and blood pressure have always been recorded simultaneously.

Mechanisms Involved.—Automatic mechanical breathing equipment for rhythmic ventilation of the airway can be classified on the basis of the cycling mechanism: (1) pressure-cycled (pressure-limited); (2) volume-cycled (pressure-limited); (3) time-cycled (pressure-limited).

Pressure cycling devices usually function on a pneumatic basis and depend upon the actuation of a diaphragm or valving mechanism by regulated pressures. They require a tight airway fit for proper cycling.

Volume cycling mechanisms depend on pneumatic or electric activation of a bellows or piston. This delivers a fixed (adjustable) stroke volume. Pressure limits must be set so that the excess volume will not be forced into the lung. A tight connection between the machine and the airway is not required. However, if a tight system is not used, a large volume must be provided in order to compensate for airway leaks.

Time cycling mechanisms usually require electrical activation (or manual timing and manipulation). Such units deliver gas at certain pressure limits on the basis of a mechanism which times the duration of the cycles and phases. A high flow rate unit can be used on either a tight system or one with a large leak.

This classifies only the actuating or cycling mechanisms of mechanical breathing equipment. Most units have additional controls for regulation of pressure, rate, inspiratory:expiratory ratio, and sometimes volume.

Fixed volume pumps may be thought to constitute a separate type of cycling mechanism. However, they represent variations of the volume cycling category. A true fixed volume pump has an inherent disadvantage in that it is impossible to know the exact volume required by patients of different sizes and ages, as well as at different times during the same procedure if there are changes in the physical characteristics of the lungs. This difficulty can be overcome by using an excess volume and providing a blowoff at certain pressure limits. However, this converts it to a volume-cycled (pressure-limited) unit. The same is true for the large piston units, such as those used with the uncuffed tracheostomy tube. Here the airway leak provides the pressure blowoff, and it also becomes volume-cycled (pressure-limited).

FLOW, PRESSURE, AND VOLUME CHARACTERISTICS OF THE NORMAL BREATHING PATTERN

Study of normal breathing curve characteristics should provide insight into the requirements for a mechanical controlled respiration pattern. We have studied three functions of the normal respiratory pattern which lend themselves to measurement. These are: (1) flow; (2) pressure; and (3) volume. These were recorded on a group of normal adult males during conscious resting breathing. Each of the test periods was preceded by at least a twenty-minute period of complete rest in order to achieve a basal ventilatory state.

Methods.—Air flow was measured by means of a pneumotachograph,[1] which recorded through a differential strain gauge on a photographic recorder. The pneumotachograph provides the most sensitive of the three ventilatory measurements since it involves an open circuit essentially free of the impedance and resistance inherent in the closed circuits used for the other determinations.

Changes in volume during normal quiet respiration were measured by means of a carefully balanced Waters-Conley Respirometer. This is the usual type of clinical equipment used to measure ventilatory pattern and volume. It is designed to measure various components of lung volume and its speed is too slow for eliciting details of curve form. The unit was therefore modified by means of a rotary motor and rheostat to provide a rapid spirogram.[2] This gives greater accuracy and detail of curve form.

There is no standard method for measuring directly the normal airway pressure pattern. With an open system, the pressure changes are instantaneous, and no significant differential can be recorded. Use of a closed system requires a large volume in order to minimize the effects of breathing against the resistance of the closed circuit. For purposes of these tests, we devised a closed system in which the subjects breathed into a 110 gallon system (two 55 gallon drums). Pressure differentials were recorded on the Poly-Viso by means of an electromanometer.

Results and Conclusions.—Typical patterns of air flow, pressure, and volume are shown in Fig. 1. Review of these tracings reveals that the normal inspiratory:expiratory duration ratio ranges between 1:1.5 and 1:2, with a mean of about 1:1.6. Slight variations occur in the same individual from time to time and between members of this group of normals. However, all subjects' tracings were within this range. As mentioned above, the pneumotachographic tracings provide the most accurate reflection of the respiratory phases since there is less resistance and inertia in this recording system.

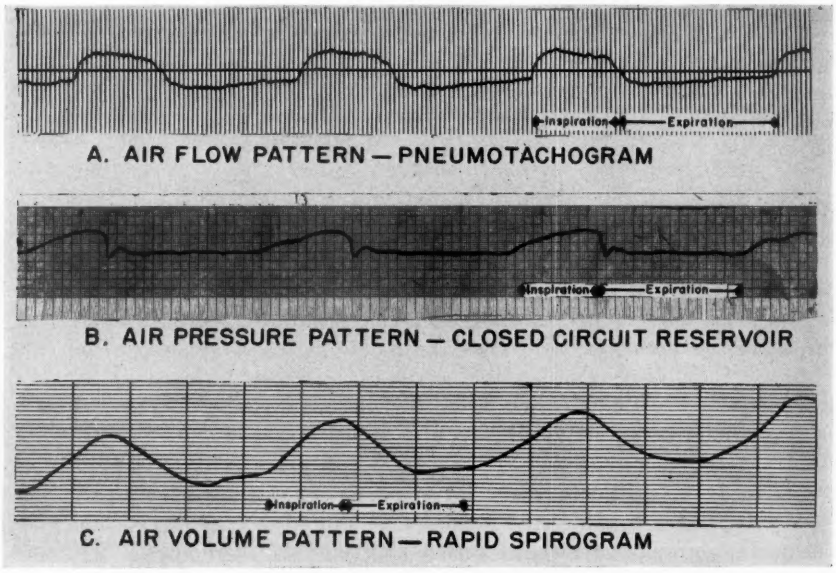


Fig. 1.—Normal, conscious, resting, breathing patterns in human beings.

The pressure pattern with the closed circuit used here reveals a curve which rises gradually to a short inspiratory plateau, followed by a precipitous expiratory pressure drop to atmospheric, with an expiratory plateau 1½ to 2 times as long as the inspiratory phase. Within the limitations of this closed circuit method, this pattern can be considered as the so-called "normal" pressure breathing curve.

The volume curves provide a similar ratio, but since they are subject to the greatest inertia and resistance, they are least informative as regards curve form.

These ratios of inspiratory:expiratory duration and the "normal" airway pressure curve provide criteria for establishing a "physiologically ideal" pressure breathing pattern.

THE AMPLITUDE OF AIRWAY PRESSURE REQUIRED DURING CONTROLLED RESPIRATION

An important consideration in controlled respiration and resuscitation is the exact amount of positive pressure required to achieve optimal alveolar

ventilation without risk of pulmonary damage or other complications. In addition, a measure of the physical effects on the lung resulting from various types of controlled breathing might offer insight into the dynamics of this form of ventilation.

Pressure-volume (PV) diagrams of the lungs and thorax have been shown to provide a measure of the physical status of the respiratory mechanism.[3] The factor of airway resistance is eliminated in static pressure-volume determinations and, accordingly, this value becomes a measure of the inherent compliance of the system.

In order to determine the amplitude of airway pressure required during controlled respiration, we have made two sets of determinations on a group of dogs: (1) initial inflation pressure-volume diagrams following normal breathing and again at end-expiration after periods of various types of controlled respiration (IPP, PNP, and INP); and (2) the end-expiratory residual lung volumes following normal breathing and these same types of controlled respiration.

Methods.—Twenty normal mongrel dogs with an average weight of 30 pounds were anesthetized with intraperitoneal pentobarbital. One-half of these were used to study the effects of various types of controlled respiration on the pressure-volume (PV) diagram of the lungs and thorax at end-expiration; the other ten dogs were used to measure the end-expiratory residual lung volume after the same types of ventilation.

Controlled respiration was administered via a tracheal cannula by means of an Anespirator.* This is a pressure-cycled unit driven by compressed gas. It has adjustable rate and positive and negative pressure controls, and produces a peaked, biphasic airway pressure curve. Machines of the pressure-cycled type usually have a constant flow rate, resulting in inspiratory and expiratory durations being approximately equal. The biphasic, peak-shaped curve, 1:1 inspiratory:expiratory ratio and cycling rate of 12 times per minute were kept constant throughout all phases.

An initial normal PV curve was obtained. Then each animal had 15-minute periods of controlled respiration with IPP (0 to 22 mm. Hg), PNP (11 mm. Hg to –11 mm. Hg), and INP (0 to –22 mm. Hg). The mechanical pressure cycling was always stopped at the end of expiration and an end-expiratory PV curve was obtained immediately after each type of breathing.

Previous investigators[3] have used the relaxation PV curve as an index of lung compliance. However, for reasons to be discussed later, we have determined the initial inflation PV curve at end-expiration in a manner similar to Nims, Conner, and Comroe.[4] The relaxation PV curve was recorded and, immediately following this determination, a second inflation PV curve was also obtained. These measurements were made by using an accurately calibrated hand pump to inject increments of air into a side arm of the tracheal cannula, allowing time for pressure stabilization (usually about 5 seconds), then reading the pressure in the closed lung-thorax system directly from a Bourdon gauge attached to the tracheal cannula. This pressure was

*Provided by E and J Manufacturing Co., Burbank, Calif.

then released, a few seconds allowed for stabilization at atmospheric pressure, and the procedure repeated at the next increment. This was continued until the pressure in the dog's closed lung-thorax system reached 40 mm. Hg.

The second group of dogs was prepared as described above. Following normal respiration and after each type of controlled respiration, the end-expiratory residual lung volume was determined by withdrawing air from the closed lung-thorax system until a pressure reading of –40 mm. Hg was achieved. The volume withdrawn at this point was recorded. In most cases, the air could be withdrawn easily at first. Then suddenly the resistance increased greatly and the withdrawal of only a few more cubic centimeters resulted in a large change in pressure. Accordingly, the end points were very sharp.

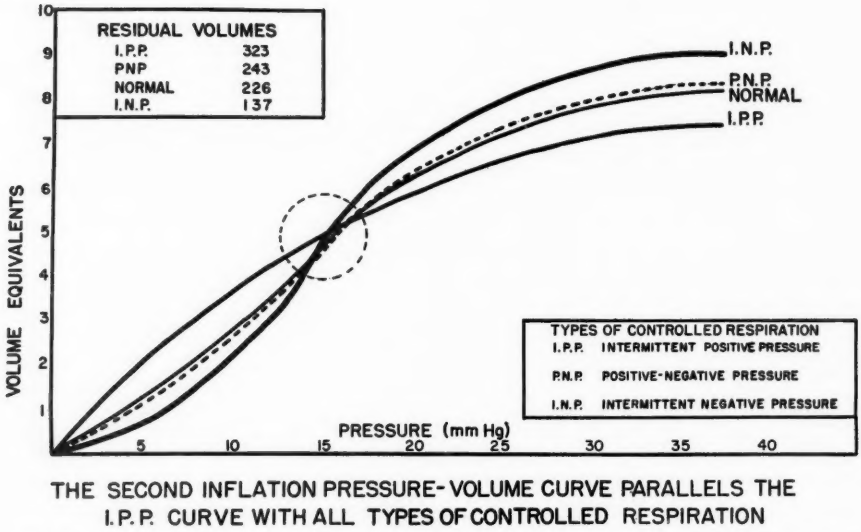


Fig. 2.—Initial inflation pressure-volume curves following various types of controlled respiration.

Results and Conclusions.—The initial end-expiratory PV curves and residual lung volumes are shown in Fig. 2.

The normal PV curve under these conditions is smoothly S-shaped. It is closely paralleled by the initial inflation PV curve following PNP controlled respiration. IPP results in a flattening of the curve, whereas INP results in accentuation of the S-shape. This means that starting reinflation of the lung after IPP is easier than after INP. This is shown in Fig. 2, where use of the same volume increments for initial reinflation results in less pressure change with IPP than with INP, during the first half of the diagram.

IPP ventilates completely within the inspiratory capacity, and the lungs remain in a partially distended state even at end-expiration. Conversely, at

end-expiration after INP breathing, the lung, which has been ventilated entirely within the expiratory reserve volume, is in a more collapsed state with a smaller volume of residual air.

Actual measurement of end-expiratory residual lung volume substantiates this impression. As indicated in Fig. 2, the residual volume is significantly greater following IPP than PNP or normal breathing, and significantly reduced after INP breathing.

However, at approximately 15 mm. Hg pressure on the PV diagram, there is an alteration in this effect resulting in an area where all of the curves intersect and cross. Below this point the curves are divergent; above this point they parallel each other. The explanation for this phenomenon has important significance.

Initial reinflation of the lung requires pressures adequate to overcome a number of forces. These include: (a) the viscoelastic properties of the lungs and thorax; and (b) the surface tension.

The viscoelastic properties of the lungs and thorax are essentially constant at any one point on the PV curve, although they may vary from point to point. However, surface tension is an additional force to be overcome primarily at the beginning of re-expansion of the lungs. At end-expiration, following INP breathing, residual lung volume is markedly diminished. In some areas, alveolar and terminal bronchiolar walls may be in apposition. The pressure required to overcome the increased surface tension is greater than that required to inflate a lung in which alveolar and terminal bronchiolar walls remain at least partially distended, such as after PNP or IPP breathing. This accounts for the greater pressure changes after INP than after IPP at the same volume increments, in the portion of the diagram below 15 mm. Hg.

This is in agreement with the finding of Radford, Lefcoe, and Mead[5] that surface tension tends to hold the walls of alveoli and bronchioles together and make the lung less compliant after complete deflation than after normal expiration.

As surface tension is overcome, inflation progresses to a point where all of the alveoli are inflated. With continued inflation, the physical properties of the INP, PNP, and IPP ventilated lungs approach each other. At the point of uniform alveolar inflation, the PV characteristics of all of these types of lungs are essentially equivalent. This corresponds to the area in which the curves intersect within the broken circle in Fig. 2.

Beyond this point the PV curves parallel each other and are essentially a function of the inherent viscoelastic properties of the lungs and thorax. However, they do remain separated because the IPP lung still has a greater volume at any one point on the curve since its inflation started with a greater initial residual volume.

In our experience, as indicated in Fig. 2, the PV curves do not all cross at a single point, but rather within a certain area. This ranges between 12 and 18 mm. Hg, with the greatest concentration of curve crossing occurring at 15 mm. Hg. According to these measurements, then, approximately 15

mm. Hg positive pressure should be used to accomplish adequate alveolar ventilation with controlled respiration. More detailed studies would probably reveal that IPP breathing requires slightly less inflation pressure than PNP breathing. These findings are similar to those of Lindskog and Bradshaw,[6] who found the threshold pressure for reinflation of experimentally produced atelectasis to be 12 to 16 cm. of water.

Relaxation PV diagrams after all methods of pressure breathing resulted in all of the curves being essentially the same and being located to the left of the initial inflation IPP curve. This is due to hysteresis.[7, 8] The second inflation PV curve similarly showed a shift to the left with all curves being essentially the same and parallel to the initial IPP curve. This is due to elimination of the surface tension factor by the initial inflation to 40 mm. Hg. These two factors are the reasons for using the initial inflation PV curve to determine the effects of the various types of pressure breathing on the physical properties of the lungs and thorax.

The above findings and Fig. 2 relate to the PV characteristics in the closed chest. An additional series of ten dogs were used to study the pressure-volume diagram following IPP and PNP breathing with the unilateral open chest. (INP breathing was not studied since dogs cannot survive this type of breathing with an open chest.)

The open chest IPP and PNP curves are similar in contour and crossing over to the closed chest curves, with the following exceptions: (1) Both curves are shifted somewhat to the left. (2) The two curves are divergent below the crossing-over point and parallel each other above this point, just as in the case of the closed chest. However, throughout their entire extent they are so close together that at no point on the curves are the differences significant. (3) The crossing-over zone occurs between 15 and 17 mm. Hg, with a mean of approximately 16.

Two factors are responsible for these differences: (1) The unilateral open chest partially eliminates the thoracic wall component of compliance, and results in the general shift of the curves to the left. (2) With one chest open, the intrathoracic negativity is lost on that side. This results in collapse of one lung during expiration, even with IPP breathing (if the lung is allowed to come to atmospheric pressure after each inspiration). Accordingly, the end-expiratory position of the lung on the open side is almost the same after either IPP or PNP breathing. This accounts for the fact that the reinflation PV curves show very little difference. Also, since the lung on the open side is more collapsed at end-expiration than in the case of the closed chest, it requires a slightly greater reinflation pressure (16 mm. Hg) to reach the crossing-over point, or zone of uniform alveolar ventilation.

THE EFFECTS OF VARYING THE POSITION AND AMPLITUDE OF THE PRESSURE BREATHING CURVE

As enumerated previously, there are five characteristics of the pressure breathing curve: (1) position; (2) amplitude; (3) inspiratory:expiratory

ratio; (4) shape; and (5) rate. In carefully controlled, comparative tests, it is not possible to evaluate all of these simultaneously. Therefore, we have used several series of tests in order to study all characteristics.

In the first series, determinations were made of the cardiorespiratory effects resulting from varying (1) the position of the pressure breathing curve (IPP, PNP, and INP), and (2) the amplitude of the pressure breathing curve (A.—total range of 22 mm. Hg; and B.—total range of 15 mm. Hg). Comparison was also made of the effects of using pure oxygen and compressed air.

The curve form, inspiratory:expiratory ratio and rate were kept constant throughout the series. An Anespirator, as previously described, was used to produce a symmetrical, biphasic, peaked curve with an inspiratory:expiratory ratio of 1:1. A cycling rate of 12 times per minute was used throughout the studies.

Methods.—Two groups of mongrel dogs, having an average weight of 40 pounds, were used. Ten dogs were used for the tests at the 22 mm. Hg range; seven dogs were used for the 15 mm. Hg range. In both groups, all dogs were evaluated at the end of each of a series of 15-minute test periods. These included: (a) an initial control period of normal breathing; (b) closed chest controlled respiration periods with intermittent positive pressure (IPP), alternating positive-negative pressure (PNP), and intermittent negative pressure (INP), using compressed air; (c) a similar closed chest comparative series using pure oxygen; (d) a repeat control period of normal breathing before the chest was opened; (e) open chest controlled respiration during IPP and PNP on compressed air; and (f) a similar open chest series using pure oxygen. In each series, all of the closed chest determinations were performed first, the phases being rotated according to calculated random. A wide unilateral thoracotomy was then performed and the open chest phases were carried out. Intermittent negative pressure (INP) was not used in the open chest series since it was found to result in the death of all dogs.

As the position of the pressure breathing curve was shifted from phase to phase in the first group of dogs, the amplitude remained the same, i.e., IPP = 0 to 22 mm. Hg; PNP = 11 mm. Hg to –11 mm. Hg; and INP = 0 to –22 mm. Hg. In the second group, the amplitude was reduced so that IPP = 0 to 15 mm. Hg; PNP = 7.5 to –7.5 mm. Hg; and INP = 0 to –15 mm. Hg.

Ether anesthesia was used and the controlled respiration was performed via a tracheal cannula. Blood pressure was monitored continuously on a Sanborn Twin Viso from a cannula in the femoral artery. Blood samples for analysis were withdrawn at the end of each 15-minute experimental period from this same cannula via a three-way stopcock. Arterial oxygen saturation was determined spectrophotometrically according to the method of Nahas,[9] and arterial pCO_2 was calculated from the nomogram of Singer and Hastings[10] after determination of pH and CO_2 content.

Results and Conclusions.—In reviewing these results, the important concept is that determination of the most efficient type of controlled respiration

requires an integrated appraisal of all of the cardiorespiratory factors studied —blood pressure, oxygen saturation, and carbon dioxide tension. Superiority of a single factor does not establish the method as the best.

The results of all phases with both groups of animals are summarized in Fig. 3. In the closed chest phases at the higher pressure range, positive-negative pressure breathing gave the greatest over-all superiority. Although

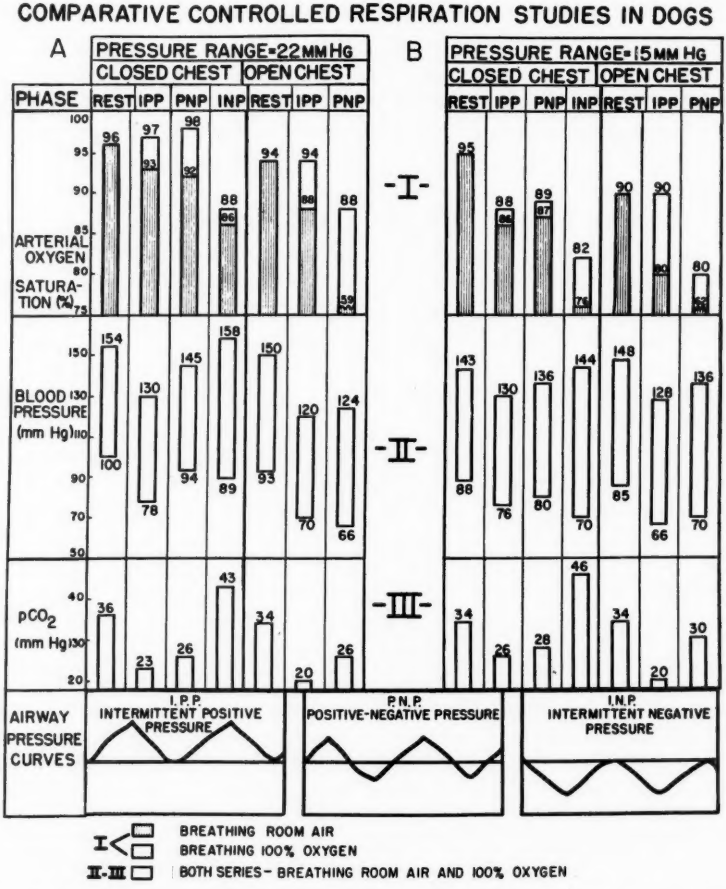


Fig. 3.—Cardiorespiratory effects of varying the position and amplitude of the controlled respiration curve in closed chest and open chest dogs.

IPP resulted in the same degree of oxygenation and carbon dioxide elimination, there was a significant difference in the blood pressure response. This resulted from the depressant effect of the high mean airway pressure with the IPP curve.

The use of INP is not clinically applicable, but was included here for the sake of completeness. The amounts of negativity applied far exceed the

usual limits of negative pressure breathing when used in conjunction with positive pressure. However, the use of this amount of negative pressure is informative since it exaggerates the resultant effects. As might be expected, blood pressure was enhanced by the negativity, but the oxygen saturation was severely depressed since the breathing was accomplished entirely within the expiratory reserve volume. This would keep the lungs fluctuating between a collapsed state and a neutral state at all times with no active alveolar inflation.

Following INP breathing, the pCO_2 was elevated above the values obtained with the other methods. The reason for this is the same as for the depressed oxygen saturation noted above, inadequate alveolar ventilation. This emphasizes an important concept, namely, carbon dioxide is not "sucked" out of the lungs by negative pressure deflation, but rather it is "flushed" out by adequate alveolar ventilation during positive pressure inflation. Further evidence of this phenomenon is revealed by the comparative arterial oxygen saturation and pCO_2 values during ventilation with compressed air and pure oxygen. Compressed air (20 per cent oxygen) always resulted in lower oxygen saturation values than did pure oxygen with all types of controlled respiration. However, the pCO_2 values were the same with either gas. Here again, elimination of carbon dioxide by any ventilating gas is a function of the alveolar flushing action resulting from the type of ventilation used, whereas the oxygen saturation is directly related to the concentration of oxygen in the ventilating medium as well as the adequacy of alveolar ventilation.

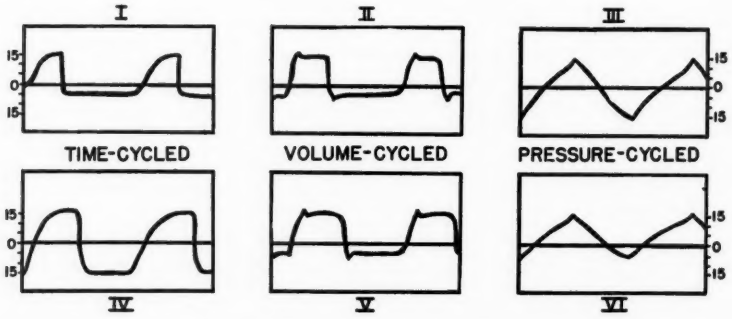
During open thoracotomy, blood pressure and oxygen saturation were always lower with any type of ventilation than with the same type in the closed chest. With the chest open, IPP breathing provided near normal oxygen saturation and the greatest elimination of carbon dioxide. Although blood pressure was slightly lower with IPP than with PNP in the open chest, the difference was not significant. The use of –11 mm. Hg negative pressure here resulted in profound depression of the arterial oxygen saturation (especially with the use of compressed air). High negativity with PNP open chest ventilation results not only in collapse of the lung on the opened side, but the mediastinum is displaced to the unopened side, resulting in some pulmonary collapse on the unopened side. This effect is more marked in the dog than in man because of the thin, unstable nature of the canine mediastinum; it is also more marked here than with the usual amounts of negativity used clinically.

For the same reasons, INP cannot be used at all during open thoracotomy in dogs. When attempted it universally results in the rapid death of the animals. Even when PNP is used on open chest dogs, the shape of the pressure breathing curve is altered because of the minimal mediastinal support. Following the positive pressure phase, the negative phase is abrupt and shortened because of rapid collapse of both lungs.

Review of Fig. 3 reveals that essentially the same relative findings resulted in the group of dogs tested at the lower pressure range (15 mm. Hg). PNP again was superior in the closed chest phases, and IPP was equally

effective with the chest opened. The arterial oxygen saturation and the carbon dioxide elimination were somewhat less than in the previous group, but this is a logical consequence of the diminished amplitude of positive pressure. Blood pressure differences were also relatively less pronounced because of the lower mean airway pressure.

Throughout all phases (except INP in the closed chest) the pCO_2 levels were maintained well below normal. This is consistent with the observation that adequate IPP or PNP controlled respiration usually results in hyperventilation apnea with respiratory alkalosis.



	I	II	III	IV	V	VI
ARTERIAL OXYGEN SATURATION (%)	95	94	93	93	92	93
pCO_2 (mm Hg)	19	20	18	20	21	20
BLOOD PRESSURE (mm Hg)	153/102	142/100	139/98	137/95	129/88	118/80
RATIO INSP/EXP	1:2	1:2	1:1	1:1	1:1	1:1
MEAN AIRWAY PRESSURE (mm Hg)	0	0+	0	0	+5	+5
RANGES	+15:-5	+15:-5	+15:-15	+15:-15	+15:-5	+15:-5

Fig. 4.—Cardiorespiratory effects of varying the curve shape and inspiratory:expiratory ratio in closed chest dogs.

THE EFFECTS OF VARYING THE SHAPE AND INSPIRATORY:EXPIRATORY RATIO OF THE PRESSURE BREATHING CURVE

In the previous studies we determined the effects of varying the position (IPP, PNP, INP) and amplitude (22 mm. Hg range, and 15 mm. Hg range) of the pressure breathing curve. Remaining characteristics to be evaluated include the curve shape and the ratio of inspiratory:expiratory duration. A carefully controlled, comparative study of these factors was performed on a group of closed chest mongrel dogs and is reported here.

Three distinctive curve shapes were evaluated (Fig. 4). The curve shape was dependent upon the automatic cycling mechanism of the machines used. All of these units were equipped with adjustable pressure controls, but the actual cycling mechanisms were of the types previously described, namely: (1) pressure-cycled; (2) volume-cycled; and (3) time-cycled.

The pressure-cycled unit (Anespirator) has a constant flow rate and builds up pressure differentials that activate a diaphragm mechanism. This produces a peaked, biphasic curve with almost straight-line slopes having approximately equivalent inspiratory and expiratory duration and sharp maximum peak pressures (Types III and VI, Fig. 4).

The volume-cycled unit (Jefferson Ventilator*) ventilates by means of a bellows mechanism. Adjustable pressure-limiting valves are used to divert the excess volume from the bellows. The volume is large and the inspiratory and expiratory strokes are rapid. Since the volume of the bellows exceeds the intrapulmonary volume required at the pressure settings used, the inspiratory and expiratory pressures are reached rapidly and the peaks of inspiration

Fig. 5.—Time-cycled controlled respiration and resuscitation unit for producing "physiologically ideal" airway pressure curve characteristics.

and expiration are cut off, resulting in flat inspiratory and expiratory plateaus and a square curve form (Types II and V). Rate and inspiratory:expiratory ratio are adjustable.

The normal closed circuit pressure pattern which we recorded earlier (Fig. 1) has a gradual pressure rise to a short inspiratory plateau followed by an abrupt fall during expiration to a prolonged expiratory plateau. The ratio of inspiratory duration to expiratory duration was between 1:1.5 and 1:2.

*Air-Shields, Inc., Hatboro, Pa.

We desired to evaluate this shape of curve also. An opportunity to do so was provided by a time-cycled, blower-type of controlled respiration unit* (Fig. 5). Independently adjustable controls are provided for rate (5 to 40 per minute), positive pressure (10 to 30 mm. Hg), negative pressure (0 to –10 mm. Hg) and ratio of inspiration to expiration (1:1, 1:2, and 1:3). The actual cycling is accomplished on the basis of the timing of the inspiratory: expiratory ratios. The unit has a high instantaneous flow rate (150 to 200 liters per minute) and produces a curve form (Types I and IV) similar to the so-called "normal" pressure breathing pattern observed earlier.

Methods.—These studies were performed on ten mongrel dogs averaging 40 pounds in weight. The dogs were prepared and determinations were made as described previously. After initial control readings were taken, each dog had all six variations of curve form shown in Fig. 4 performed for 15-minute periods each. Blood pressure, arterial oxygen saturation, and pCO_2 were measured at that time. The curve forms were rotated in their order of performance.

This protocol provides a critical comparison not only of three curve shapes and two inspiratory:expiratory ratios (1:1 and 1:2) produced by three types of cycling mechanisms, but also incorporates a cross comparison of two pressure ranges (15 to –5 mm. Hg, and 15 to –15 mm. Hg) and two mean mask pressures (zero and +5 mm. Hg). Having previously considered the issues of curve position and amplitude, this series of tests should provide the additional data required to evolve the physiologically ideal controlled respiration curve characteristics.

Results and Conclusions.—Fig. 4 reveals that all of these curve shapes and inspiratory-expiratory ratios provide essentially the same degree of oxygenation and carbon dioxide elimination. This is a reflection of the adequacy of alveolar ventilation resulting from curves with positive pressure phases of 15 mm. Hg. The oxygen saturation of Curves I and II is slightly, but not significantly, higher than observed with the other curves.

All curves have an inspiratory:expiratory ratio of 1:1, except Curves I and II, which have a 1:2 ratio. The two curves (V and VI) with a positive mean airway pressure (+5 mm. Hg) had a blood pressure reading significantly below the other curves, which had mean airway pressures of zero. The effect of an elevated airway pressure in reducing cardiac output and arterial pressure has been well documented by previous investigators.[11-17] It is important to note that these blood pressure effects resulting from elevation of the mean airway pressure occurred in essentially normal animals. The studies of Maloney and associates[12] and Hubay and co-workers[18] have indicated that the circulatory effects of pressure breathing are accentuated in the presence of hypovolemia or shock.

However, in Curves I through IV, where the mean airway pressure was maintained at zero, marked differences in blood pressure still occurred. Curves III and IV showed greater circulatory depression than Curves I and II. This could not have resulted from the greater negativity used in these

*Developed by E and J Manufacturing Co., Burbank, Calif.

instances since our previous studies (Part III) and Whittenberger's review of the subject[7] have indicated that negativity enhances circulatory effects in the closed chest. Curves I and IV have the same shape, so curve form per se could not be the cause of this difference in arterial blood pressure. The remaining difference between Curves I and II and Curves III and IV is the ratio of inspiratory:expiratory duration. The former have a 1:2 ratio and the latter a 1:1 ratio. At any one pulse rate, the curve with a 1:1 ratio has a greater number of heartbeats during the positive pressure than a curve with a 1:2 ratio. This factor accounts for the circulatory superiority of Curves I and II.

Motley and co-workers[13] emphasized this point in their careful studies of intermittent positive pressure breathing. They showed that positive airway pressure during inspiration results in decreased net filling pressure and decreased cardiac output from the right heart. A rapid fall in pressure during expiration results in an increase in net filling pressure leading to an increase in cardiac output. With the expiratory duration exceeding the inspiratory, the heart is able to compensate for the impairment due to pressure breathing.

During inspiration the left heart briefly increases its output (for 3 to 5 beats) due to increased filling by blood squeezed out of the lungs. However, after a short interval the effect of reduction in right heart output is transmitted to the left heart, resulting in a fall in left heart output and a reduction in arterial pulse pressure. Therefore, it is important to provide a longer expiratory phase. This permits more heartbeats during expiration, which allows the heart to compensate for the decreased output occurring during positive pressure inspiration.

Werko's studies[19] on the effects of positive pressure breathing on the circulation in man further emphasize the importance of the beat-to-beat effect and the advantage of a rapid fall in expiratory pressure with an expiratory phase exceeding the inspiratory in duration.

Although Curves I and II both have an inspiratory:expiratory ratio of 1:2, the same amplitude of pressure change, and the same mean airway pressure, the former curve reveals less impairment of blood pressure. This effect, then, must be related to the curve form. A beat-to-beat analysis again provides the explanation. With Curve II, all of the heartbeats during the inspiratory phase are during maximum pressure, due to the square curve form. During inspiration with Curve I, maximum pressure is exerted only during the terminal inspiratory plateau portion of this phase, thereby resulting in less detriment to circulation.

This beat-to-beat blood pressure effect can easily be demonstrated by monitoring the continuous simultaneous record of arterial blood pressure and controlled respiration breathing curve. Fig. 6 illustrates that when a 1:2 ratio is used, the beat-to-beat effect on blood pressure is a rise during two-thirds of the respiratory cycle and a fall during one-third of the cycle. In the final analysis, Curve I most nearly approaches the "physiologically ideal" airway pressure curve. Such a curve must have an adequate inspiratory plateau to provide uniform alveolar ventilation for arterial oxygen saturation

and carbon dioxide elimination. However, the inspiratory positive pressure must be sustained only long enough for optimal ventilatory effects, with minimal detriment to the circulatory system.

The 1:2 inspiratory:expiratory ratio is usually best. However, there are instances where special circumstances dictate the use of a different ratio. In the lung which has decreased compliance (pulmonary edema, fibrosis, etc.), obstruction (secretions), or increased resistance (bronchospasm) it becomes necessary to reduce the flow rate, increase the pressure, or augment the inspiratory duration, or use a combination of these techniques. In such a situation it may prove beneficial to use a 1:1 ratio of inspiratory:expiratory duration, at least temporarily.

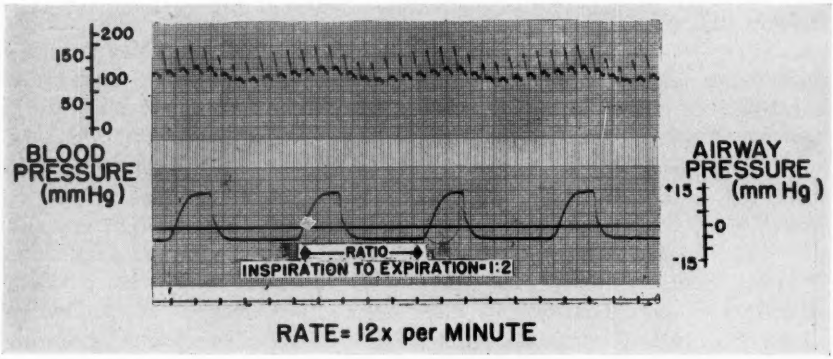


Fig. 6.—Beat-to-beat circulatory effects with "physiologically ideal" PNP breathing curve.

In the asthmatic or emphysematous chest, expiratory flow is the ventilatory problem. In addition to slowing the rate, in such instances it may also be necessary to use a 1:3 inspiratory:expiratory ratio.

CLINICAL APPLICATION OF VARYING THE CHARACTERISTICS OF THE PRESSURE BREATHING CURVE IN CLOSED AND OPEN CHEST HUMAN BEINGS

The previous portions of this work have detailed, controlled, comparative studies of the effects of the various characteristics of the pressure breathing curve on the cardiorespiratory dynamics of closed and open chest dogs. On a practical basis, it becomes important to determine the applicability of these findings to human beings.

Two series of studies were performed on human beings:

1. *Open chest:* Twelve patients were studied during exploratory thoracotomy for resection of various types of pulmonary pathology, including tuberculosis, bronchiectasis, carcinoma, and granuloma. In each case, as soon as the chest was opened, the extent and nature of the pathology were determined, but the resection per se was not performed until after the completion of four ten-minute test periods with various forms of controlled respiration. In this way, each patient represented a completely controlled series, since the effects of extraneous factors, such as surgical manipulation, hemorrhage, pul-

monary compression, etc., were eliminated and the observed cardiorespiratory effects reflected only the dynamics resulting from the controlled respiration.

2. *Closed chest:* The other group consisted of twelve normal adult male student volunteers in whom controlled respiration studies under anesthesia were performed with the chest closed.

Methods.—After being anesthetized and intubated with a cuffed endotracheal tube, each subject and patient had an indwelling polyethylene catheter placed in the femoral artery. By means of a three-way stopcock, isotonic saline was infused to keep the catheter open, blood pressures were recorded on a Sanborn Poly-Viso via a Statham strain gauge and amplifier, and blood samples were withdrawn for determination of pCO_2.

Arterial oxygen saturation was determined by means of a Wood direct reading ear oximeter[20] converted to record on a direct writing potentiometer.[21] The nomogram of Singer and Hastings[10] was used to calculate pCO_2, as noted previously.

During the closed chest studies, initial control determinations were first made on the anesthetized subjects. Then each was evaluated during four ten-minute test periods of controlled respiration. These consisted of: (1) IPP breathing at 0 to 15 mm. Hg by means of the pressure-cycled Anespirator, which gives peaked, biphasic curves and a 1:1 ratio of inspiration to expiration; (2) IPP breathing at 0 to 15 mm. Hg by means of the E and J time-cycled controlled respiration unit, which provides a physiologically ideal shaped curve and a 1:2 ratio; (3) PNP breathing at 15 mm. Hg to –5 mm. Hg with the Anespirator; and (4) PNP breathing at 15 mm. Hg to –5 mm. Hg with the E and J controlled respiration unit. The methods were rotated randomly in their order of performance.

The patients undergoing thoracotomy had a set of closed chest control determinations made during surgery before the pleura was opened. Open chest control determinations were made after the lung had been freed up and the nature and extent of the pathology determined. Each patient was then evaluated at the end of the same four test periods of controlled respiration as described for the closed chest human beings. The regular closed circuit of the anesthesia machine is used for these controlled respiration units. The pressure variations are exerted on an anesthesia breathing bag suspended in an airtight plastic globe.

Results and Conclusions.—In both the closed and open chest human series, the over-all findings were in agreement with those observed on dogs in the preceding sections. Fig. 7 reveals that in the closed chest better results are obtained for blood pressure, oxygen saturation, and pCO_2 with both types of curves during PNP breathing than with these same curves during IPP breathing. However, the ideal PNP controlled respiration curve provides the optimal arterial oxygenation, carbon dioxide elimination, and blood pressure elevation in closed chest cases.

In the open chest patients, the ideal IPP controlled respiration curve provided the most satisfactory over-all effects as regards oxygen saturation, carbon dioxide elimination, and maintenance of blood pressure. Both IPP

curves provided better oxygenation and CO_2 elimination than did the same curves during PNP breathing. The use of a negative pressure phase with open chest human cases did not elevate blood pressure significantly, and resulted in less effective arterial oxygen saturation and carbon dioxide elimination. This is in agreement with our findings in the dogs.

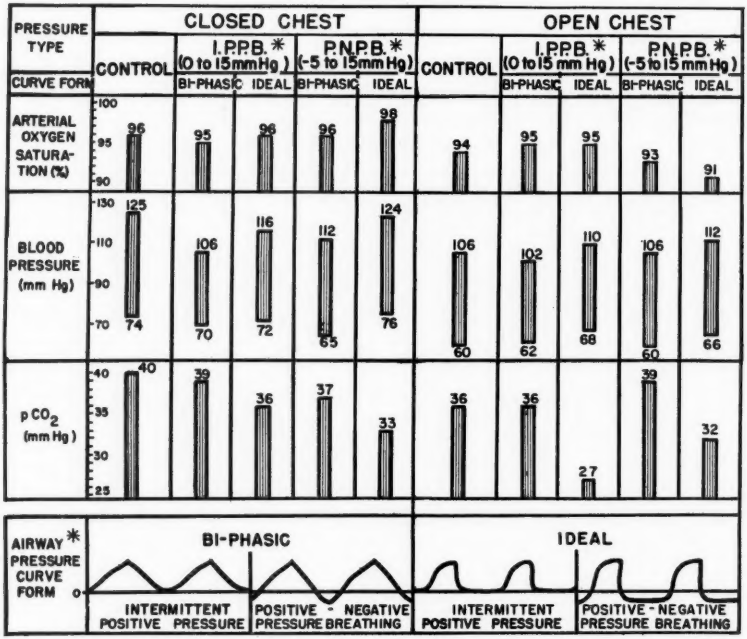


Fig. 7.—Cardiorespiratory effects of controlled respiration in open and closed chest human beings.

Throughout these human studies the results show a consistent trend, i.e., PNP breathing is superior in the closed chest, the use of a negative phase does not serve any significantly useful purpose in the open chest, and the curve with the ideal characteristics produces superior cardiorespiratory effects with either IPP or PNP breathing. Sometimes the actual differences between the methods are not great. However, in all instances, they corroborate the previous findings in the dog studies. Furthermore, all of these closed chest and open chest human studies were carried out under carefully controlled conditions with the subjects and patients maintained in an essentially normal state. As previously pointed out, these cardiorespiratory effects are known to be accentuated by shock, hemorrhage, cardiovascular instability, etc.

Rate: Detailed controlled studies of cycling rate were not performed in any of these tests. However, we found that a near-normal cycling rate of 12 times per minute provides normal oxygenation and carbon dioxide elimination in most adult cases. Slowing the rate below this level can result in ventilatory insufficiency. Significantly faster rates do not usually aid ventilation or

circulation and serve further to eliminate carbon dioxide, which is already reduced to an alkalotic level by a rate of 12 per minute. If rate becomes too fast, the inspiratory phase can be shortened to the point where inadequate alveolar ventilation results.

No controlled respiration studies were carried out on infants or children. Goddard and associates[22] have shown that newborn resuscitation requires special consideration of pressure and time relationships. However, for infants and children beyond this neonatal stage, the same curve form and characteristics should be used as with adults, with the exception of the rate. According to the nomogram of Radford,[23] infant respiratory rates range between 30 and 50 and children between 18 and 30. For controlled respiration, a rate approaching these normal levels should be used.

Manual controlled respiration: Controlled respiration in the form of manual compression of the anesthesia bag is still used more frequently in most hospitals than automatic controlled respiration. The principles elucidated here regarding the cardiorespiratory effects of the curve form and characteristics apply equally to this form of controlled respiration. It is not possible to administer a negative phase with the usual anesthesia machine. However, intermittent positive pressure can be administered by means of a curve which is as physiologically ideal as that obtained with an automatic device.

Fig. 8, *A*, shows such a manual controlled respiration pattern and, in the table below, illustrates the minimally depressant effect it has on blood pressure. Fig. 8, *B*, *C*, and *D* reveals the deleterious circulatory effects which result from increasing the airway pressure by incomplete release of the anesthesia bag, sustaining the inspiratory phase too long, and too rapid cycling.

A physiologically ideal breathing curve should be the goal in resuscitation and controlled respiration by either manual or mechanical means.

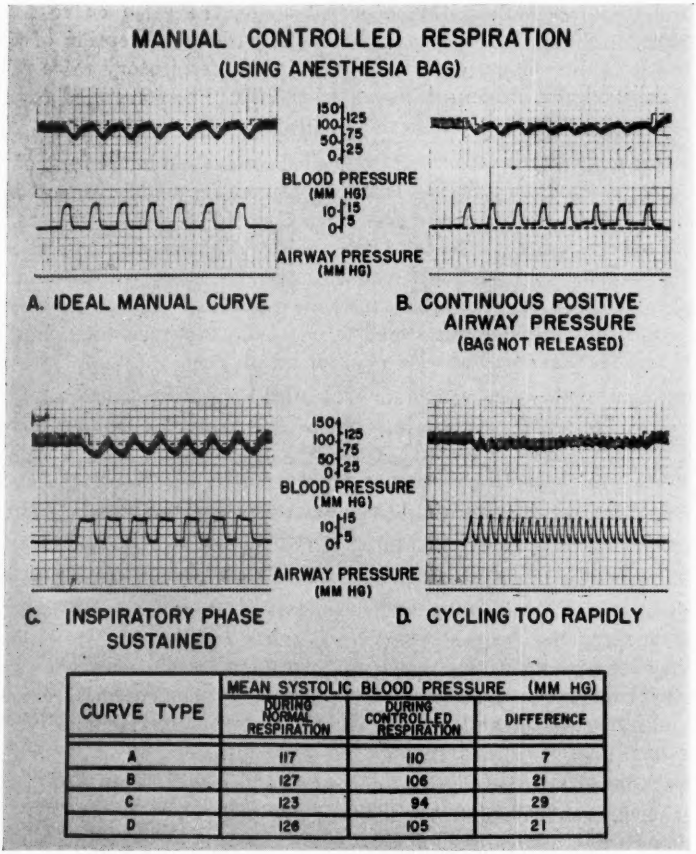
Hyperventilation alkalosis: The hazard of respiratory acidosis during thoracic surgery has been stressed by Beecher and Murphy.[24] It has been re-emphasized by others and shown to be present in depressed states and resuscitative conditions. Dripps and Severinghaus[25] have recently reviewed the effects of hypercarbia, and Brown, Miller, and co-workers[26, 27] have studied the serious results of rapid carbon dioxide elimination.

However, as revealed in all of our studies, the use of automatic controlled respiration prevents respiratory acidosis, except in the case of INP (Fig. 3), which is not used clinically. All methods of mechanical breathing which were considered adequate resulted in hyperventilation alkalosis, as indicated by the depressed pCO_2 values. This raises the question of whether the alkalosis resulting from passive hyperventilation can be deleterious.

Active hyperventilation requires energy expenditure and results in tetany and loss of consciousness. However, there has never been well-substantiated evidence that passive hyperventilation alkalosis, such as that resulting from use of tank respirators or controlled respiration units, is dangerous or deleterious. Morch, Saxton, and Gish[28] have reported keeping patients in hyperventilation alkalosis for long periods of time without any apparent difficulty.

However, Crane, Affeldt, Austin, and Bower[29] have come to question the desirability of this condition on the basis of their findings in poliomyelitis patients.

For the present, it is generally assumed that passive hyperventilation alkalosis does not have serious consequences, at least when only used for limited periods during controlled respiration or resuscitation.



CURVE TYPE	MEAN SYSTOLIC BLOOD PRESSURE (MM HG)		
	DURING NORMAL RESPIRATION	DURING CONTROLLED RESPIRATION	DIFFERENCE
A	117	110	7
B	127	106	21
C	123	94	29
D	126	105	21

Fig. 8.—Comparison of ideal and other breathing curves obtained by manual controlled respiration by means of anesthesia breathing bag.

Negative pressure phase in open chest: Divergent opinions persist regarding the usefulness of a negative pressure phase in open chest controlled respiration. Gibbon and Haupt,[30] Nealon and associates,[31] and Allbritten and co-workers[32] advocate a negative expiratory phase in the open chest. They find that negative pressure during deflation lowers mean airway pressure, although they use an inspiratory:expiratory ratio of 1:1, which raises mean airway pressure.

Björk, Engström and associates[33] use a volume-cycled positive-negative pressure device for controlled respiration during thoracic surgery, but they state, "In the open thorax, the effect on the circulation of a negative phase and a low mean pressure may be less."

Hubay, Ankeney, and co-workers[18, 34] have used a bristle flowmeter to measure the beat-to-beat effect of IPP and PNP breathing. They find that in the open chest ". . . the interposition of a negative phase between positive pressure lung inflations does not benefit the circulation significantly." This is in agreement with our findings in animals and human beings.

Waltz, Hubay, Ankeney, and Merrill[35] have studied the pulmonary histopathology following positive and negative pressure respiration. They found that negative pressure in the open chest results in complete collapse of bronchioles at lower pressures. Accordingly, they recommend that effective pulmonary ventilation can be accomplished with minimal lung damage at a positive pressure range of +15 to +20 cm. of water and a negative pressure range of –5 cm. of water. The collapse of terminal bronchioles with negative pressure probably accounts for the high pCO_2 observed in our dogs subjected to INP of zero to –22 mm. Hg. This collapse tends to trap air in the alveoli and prevent adequate flushing out. As mentioned previously, carbon dioxide must be flushed out of the alveoli rather than being sucked out.

Although our results similarly indicate that a negative expiratory phase serves no significant purpose in the open chest, we recognize that there are certain situations in which a small amount of negativity may be advisable: (1) In emphysematous lungs, negative pressure may be helpful in assisting deflation. (2) Where there is expiratory resistance due to a narrow endotracheal tube, a negative expiratory phase may prevent overdistention. (3) Use of a very rapid cycling rate may allow insufficient time for adequate deflation without the addition of a negative phase. (4) Overdistention from any cause may hinder the surgeon and necessitate negative pressure deflation to reduce obscuration of the field.

If negativity is used, it need not exceed –5 mm. Hg if the curve shape and inspiratory:expiratory ratio are physiologic. Excessive negativity promotes complete collapse of the lung in the open chest. This lung may then constitute a venoarterial shunt,[25] and it also requires more than the usual pressures for reinflation.

SUMMARY AND CONCLUSIONS

1. Carefully controlled, comparative tests, performed on both open and closed chest dogs and human beings, have established the characteristics of the "physiologically ideal" controlled respiration curve (Fig. 6) on the basis of arterial oxygen saturation, pCO_2 and blood pressure determinations. These are:

Shape: The curve should have a gradual pressure rise to a short inspiratory plateau, followed by an abrupt expiratory fall to a longer expiratory plateau.

Position: Positive-negative pressure (PNP) provides over-all superior controlled respiration in the closed chest. This is due to the effect of the negative phase in lowering mean airway pressure so that the deleterious effect of the

inspiratory positive pressure on cardiac refill (and ultimately on cardiac output and arterial blood pressure) can be compensated for during the expiratory phase. With the open chest, the use of a negative pressure phase provides no significant circulatory benefit and, if excessive, may be deleterious as regards ventilation. IPP breathing is recommended in the open chest, except under special circumstances which have been detailed.

Amplitude: Positive pressure of approximately 15 mm. Hg is required to provide uniform alveolar ventilation. This influences both oxygenation and carbon dioxide elimination. Negative pressure, when used, serves only to lower the mean airway pressure in the closed chest, thereby avoiding circulatory embarrassment. With the unilaterally open chest the lung can collapse after each inspiratory phase, due to loss of intrathoracic negativity. Pressure-volume studies indicate that slightly more pressure is usually required for adequate reinflation in the open chest than in the closed chest. With a properly shaped curve, a low mean airway pressure can be attained even with these positive pressure phases. The usual PNP range for the closed chest should be approximately 15 mm. Hg to –5 mm. Hg, and the usual IPP range for the open chest should be approximately zero to 16 mm. Hg.

Inspiratory:expiratory ratio: For both PNP and IPP in the open or closed chest, a 1:2 ratio of inspiration to expiration provides optimal ventilation and is least deleterious to the circulation. The duration of inspiratory positive pressure influences the blood pressure on the basis of the mean airway pressure and the number of heartbeats during the positive phase. Under certain conditions, which we have detailed, it may be advantageous to vary this ratio.

Rate: A controlled respiration rate of 12 per minute was found to be adequate for most adults. For infants and children the rate should be increased and varied according to their age and size.

2. This curve form compares favorably with the so-called normal airway pressure pattern obtained by use of a large closed circuit reservoir.

3. This curve form and characteristics can be produced by a time-cycled controlled respiration and resuscitation unit. Such a device was used for these studies.

4. This curve form and characteristics can also be produced by manual compression of the anesthesia bag (IPPB only).

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(For Discussion, see page 474.)

THE SIGNIFICANCE OF THE LUNG-THORAX COMPLIANCE IN VENTILATION DURING THORACIC SURGERY

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ADEQUATE pulmonary ventilation during anesthesia is essential for maximum protection of the patient during surgical operations. Previous studies of arterial pH, pO_2, and pCO_2 during general anesthesia for surgical operations have shown that the usual methods of providing ventilation fail to maintain a consistently normal pCO_2 level with consequent development of respiratory acidosis.[1-8] In some cases, the arterial pCO_2 was elevated two or three times above the normal level. Inadequate ventilation was found to occur more often during intrathoracic operations, especially during pneumonectomy. It has been found that the effective ventilation was often decreased during intrathoracic operations and a considerable increase in minute volume was required to provide adequate effective ventilation.[4, 7, 9] Adding assistance to the deflation phase of respiration, as well as to the inflation phase, provided consistently adequate ventilation without excessive elevation of airway pressure.[9] This was primarily due to an increase in the ventilatory volume. The ventilatory efficiency remained disappointingly low.

The change of the volume of gas in the respiratory system per unit increase of the intratracheal pressure is a measure of the distensibility of the lungs and the restriction to expansion imposed by surrounding structures. This relationship of airway pressure to the volume of gas within the respiratory system is termed lung-thorax compliance,[10] a factor directly related to the total volume. In the determination of factors responsible for the inefficiency of ventilation during thoracic operations, the lung-thoracic compliance was studied. This paper presents a study of measurements of lung-thorax compliance made in anesthetized and unanesthetized patients with normal and diseased respiratory systems preceding, during, and following intrathoracic surgical operations.

METHODS AND SUBJECT MATERIAL

The methods used in this study have been described elsewhere in detail.[11] The method used to determine the lung-thorax compliance in the anesthetized patients was basically that described in 1946 by Rahn, Otis, Chadwick, and

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Fenn.[12] The unanesthetized patients were allowed to inhale, the airway was occluded and the airway pressure was measured with a pressure transducer (Statham P23A) during a state of voluntary complete relaxation. The airway occlusion was released and the volume of passively exhaled gas was measured through a pneumotachograph by the electronic integration of rate of gas flow against time. This was repeated 20 to 25 times and a volume/pressure curve was plotted as shown in Fig. 1. The average value was termed

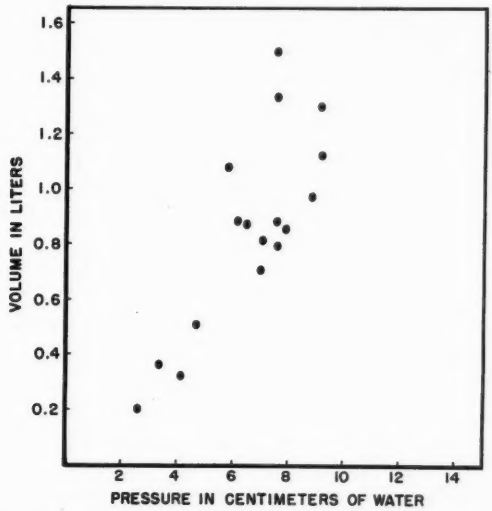

Fig. 1.—Lung-thorax compliance (anesthetized). (Reprinted through courtesy of A.M.A. Archives of Surgery.)

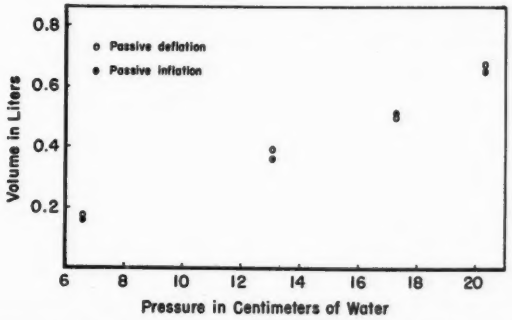

Fig. 2.—Lung-thorax compliance (awake). (Reprinted through courtesy of A.M.A. Archives of Surgery.)

the lung-thorax compliance and was expressed as milliliters of gas per centimeter of H_2O pressure change. Multiple readings were required to obtain statistically significant results because of the scattering of the plotted points. "Training" of the patients was not used to increase the degree of relaxation nor were any "inaccurate" readings discarded once the study was started.

This was to prevent bias which was found to occur readily in preliminary tests when "training" of the subjects or "selecting" of results was employed. A permanent photographic record was made of all measurements as they appeared on the oscilloscope.

During anesthesia, the airway pressure was measured as the lungs were inflated with oxygen during a period of apnea produced by hyperventilation or by neuromuscular blocking agents. The airway was occluded and the intratracheal pressure was measured. The airway occlusion was released and the amount of passive exhaled gas was measured. This was repeated 3 to 6 times in succession during which time all factors influencing lung-thorax compliance were kept constant. Immediately following this, the factor under investigation was changed and 3 to 6 more measurements were taken in succession. The volume/pressure values during inflation and deflation (6 to 12 readings) were averaged to give the mean lung-thorax compliance for each factor measured. The plotted points were virtually linear during anesthesia as shown in Fig. 2 and permitted valid comparison of relatively small changes in compliance with relatively few measurements.

RESULTS

1. *Lung-Thorax Compliance of Controls.*—The lung-thorax compliance of 9 normal, unanesthetized individuals was measured on 32 separate occasions. These individuals comprised the normal control group. All measurements were made in the supine position without sedation and before surgical operation. The results are shown in Table I. The average lung-thorax compliance was 240 ml./cm. H_2O.

2. *The Effect of Cardiac Disease and Pulmonary Disease on Lung-Thorax Compliance.*—The lung-thorax compliance was measured in a group of 9 un-

TABLE I. EFFECT OF CARDIAC DISEASE AND PULMONARY DISEASE ON LUNG-THORAX COMPLIANCE*

NORMAL CONTROLS		CARDIAC DISEASE			PULMONARY DISEASE		
CASE NUMBER	COMPLIANCE (ML./CM. H_2O)	CASE NUMBER	DISEASE	COMPLIANCE (ML./CM. H_2O)	CASE NUMBER	DISEASE	COMPLIANCE (ML./CM. H_2O)
N_1	350	C_1	Mitral stenosis	220	P_1	Bronchiectasis	80
N_2	400	C_2	Mitral stenosis	140	P_2	Bronchiectasis	290
N_3	130	C_3	Mitral stenosis	70	P_3	Bronchiectasis; empyema	210
N_4	150	C_4	Mitral stenosis	100	P_4	Lung carcinoma	130
N_5	260	C_5	Mitral stenosis	210	P_5	Lung carcinoma	90
N_6	170	C_6	Patent ductus arteriosus	80	P_6	Lung carcinoma	110
N_7	210	C_7	Patent ductus arteriosus	220	P_7	Metastases to lung	240
N_8	310	C_8	Cor pulmonale; emphysema	90	P_8	Emphysema; cor pulmonale	90
N_9	170	C_9	Cor pulmonale; emphysema	60	P_9	Emphysema; cor pulmonale	60
		C_{10}	Pulmonic stenosis	170			
		C_{11}	Pulmonic stenosis	120			
9 Cases	Average 240	11 Cases		Average 130	9 Cases		Average 140

*Unanesthetized.

anesthetized patients with pulmonary disease. All measurements were made in the supine position without sedation and before surgical operation. The results are also shown in Table I. The average lung-thorax compliance was 130 ml./cm. H_2O in the group with cardiac disease and 140 ml./cm. H_2O in the group with pulmonary disease. When the "t" test was employed, the difference in compliance between the normal control group and the cardiac disease group was found to be statistically significant at the one per cent level. The difference between the normal control group and the pulmonary disease group was significant between the one per cent and 5 per cent level. No significant difference in compliance existed between the patients with cardiac disease or pulmonary disease.

3. *Lung-Thorax Compliance in Unanesthetized Patients Before and After Intrathoracic Surgery.*—A group of 13 patients undergoing intrathoracic surgery was studied to determine if a change in lung-thorax compliance occurred during the operation and early postoperative period. The lung-thorax compliance was measured in the unanesthetized state in the supine position without sedation on the day preceding the operation. The lung-thorax compliance was measured in a similar manner on the fifth postoperative day or as soon thereafter as possible. The results are shown in Table II. There was a decrease in lung-thorax compliance from an average of 170 ml./cm. H_2O preoperatively to an average of 110 ml./cm. H_2O postoperatively. This difference was found to be statistically significant between the one per cent and 5 per cent level when the "t" test was employed.

TABLE II. LUNG-THORAX COMPLIANCE IN UNANESTHETIZED PATIENTS BEFORE AND AFTER INTRATHORACIC SURGERY

CASE NUMBER	OPERATION	PREOPERATIVE COMPLIANCE (ML./CM. H_2O)	POSTOPERATIVE COMPLIANCE (ML./CM. H_2O)
C_1	Mitral valvotomy	220	80
C_5	Mitral valvotomy	210	50
C_6	Division patent ductus	80	60
C_7	Division patent ductus	220	180
C_{10}	Pulmonic valvotomy	170	200
C_{11}	Pulmonic valvotomy	120	120
P_1	Lobectomy	80	70
P_2	Lobectomy	290	130
P_3	Lobectomy	210	120
P_4	Pneumonectomy	130	50
P_6	Pneumonectomy	110	100
P_7	Thoracotomy	240	200
P_8	Excision of bullae	90	90
13 Cases		Averages 170	110

4. *The Effect of General Anesthesia on Lung-Thorax Compliance.*—A group of 11 patients undergoing intrathoracic surgery was studied to determine if any change occurs during general anesthesia. The lung-thorax compliance was measured in the unanesthetized, unsedated, supine patient on the day preceding surgery. The compliance was measured again in the anesthetized, supine patient preceding the initiation of the operation. Several different types of general anesthetic agents were used. Apnea was obtained either by hyperventilation or by a combination of hyperventilation and neuromuscular

blocking agents. The compliance appeared to be independent of the method of producing apnea. The results are shown in Table III. There was a large, consistent decrease in the lung-thorax compliance from an average of 170 ml./cm. H_2O in the unanesthetized state to an average of 47 ml./cm. H_2O in the anesthetized state. The average decrease was 67 per cent.

TABLE III. EFFECT OF GENERAL ANESTHESIA ON LUNG-THORAX COMPLIANCE

CASE NUMBER	ANESTHETIC AGENT (1)*	APNEA INDUCED (2)*	UNANESTHETIZED COMPLIANCE (ML./CM. H_2O) (3)*	ANESTHETIZED COMPLIANCE (ML./CM. H_2O) (4)*	COMPLIANCE CHANGE (PER CENT)
C_2	T., E.	H., S.	140	42	-70
C_4	C.	H.	100	29	-71
C_5	C.	H.	210	49	-77
C_7	C.	H., S.	220	29	-87
C_{10}	T., C., E.	H., Sy.	170	47	-72
C_{11}	T., E.	H., Sy.	120	49	-59
P_2	C.	H.	290	46	-84
P_3	T., E.	H., S.	210	62	-71
P_5	T.	H., S.	90	50	-44
P_7	C.	H.	240	57	-76
P_8	C., E.	H.	90	61	-32
11 Cases		Averages	170	47	-68

*(1) E. = Ether; T. = Thiopentothal; C. = Cyclopropane.
(2) H. = Hyperventilation; S. = Succinylcholine; Sy. = Syncurine.
(3) All measurements taken in supine position the day preceding operation.
(4) All measurements taken in supine position before start of operation.

5. *The Effect of the Lateral Position on Lung-Thorax Compliance.*—A group of 7 patients undergoing intrathoracic surgery was studied to determine if any change in lung-thorax compliance occurs with a shift from the supine position to the lateral position. The lung-thorax compliance was measured in the anesthetized state prior to the onset of surgery. The measurements were made just before and just after the position was changed in order to keep all other factors influencing lung-thorax compliance as constant as possible. The results are shown in Table IV. The changes in lung-thorax compliance that occurred were quite variable, ranging from a decrease of 47 per cent to an increase of 14 per cent with an average decrease of 10 per cent. In a separate series of patients undergoing miscellaneous types of surgery, obesity was found to be an important factor influencing lung-thorax compliance.

TABLE IV. EFFECT OF LATERAL POSITION ON LUNG-THORAX COMPLIANCE

CASE NUMBER	DISEASE	COMPLIANCE IN SUPINE POSITION (ML./CM. H_2O)	COMPLIANCE IN LATERAL POSITION (ML./CM. H_2O)	COMPLIANCE CHANGE (PER CENT)
C_2	Mitral stenosis	42	48	+14
C_5	Mitral stenosis	49	41	-16
C_7	Patent ductus arteriosus	29	33	+14
P_2	Bronchiectasis	46	47	+2
P_3	Bronchiectasis; empyema	62	33	-47
P_5	Lung carcinoma	50	33	-34
P_8	Emphysema; cor pulmonale	61	59	-3
7 Cases				Average -10

There was an average increase in the lung-thorax of 136 per cent in one very obese patient with the shift from the supine to the lateral position. Her ventilatory effort dramatically improved as the heavy pendulous breasts and the anterior abdominal wall fell away from the thorax and abdomen. Repeated measurements confirmed this striking change.

6. *The Effect of the Open Chest on Lung-Thorax Compliance.*—A group of 5 patients undergoing intrathoracic surgery was studied to determine if any change in lung-thorax compliance occurs when the chest is opened. The lung-thorax compliance was measured in the anesthetized state prior to opening the chest and was measured again after the Finochietto rib spreader was in place but before the lung was packed or retracted to gain exposure. Other factors influencing compliance, such as position of the patient and depth of anesthesia, were kept as constant as possible. The results are shown in Table V. The change in lung-thorax compliance ranged from –19 per cent to +95 per cent, a rather wide range. There was an increase in compliance in 4 of the 5 cases with an average increase of 45 per cent for the entire group.

TABLE V. EFFECT OF OPEN CHEST ON LUNG-THORAX COMPLIANCE

CASE NUMBER	COMPLIANCE OF CONTROL (ML./CM. H_2O)	COMPLIANCE WITH CHEST OPEN (ML./CM. H_2O)	COMPLIANCE CHANGE (PER CENT)
C_4	31	25	-19
C_5	41	80	+95
C_{10}	47	59	+26
C_{11}	49	52	+6
P_2	47	74	+58
5 Cases			Average +45

7. *The Effect of the Open Chest and Retraction of the Lung on Lung-Thorax Compliance.*—A group of 7 patients undergoing intrathoracic surgery was studied to determine if any change in lung-thorax compliance occurs with retraction against the lung. The lung-thorax compliance was measured in the anesthetized state prior to opening the chest and was measured again after the Finochietto rib spreader was in place and the lung had been packed and retracted to gain exposure. Other factors influencing compliance, such as position of the patient and depth of anesthesia, were kept as constant as possible. The results are shown in Table VI. The change in lung-thorax

TABLE VI. EFFECT OF OPEN CHEST AND RETRACTOR ON LUNG-THORAX COMPLIANCE

CASE NUMBER	COMPLIANCE OF CONTROL (ML./CM. H_2O)	COMPLIANCE WITH RETRACTOR (ML./CM. H_2O)	COMPLIANCE CHANGE (PER CENT)
C_2	48	38	-21
C_7	33	28	-15
C_{12}	30	12	-60
P_2	47	49	+4
P_4	33	29	-12
P_6	31	31	0
P_8	59	51	-14
7 Cases			Average -17

compliance ranged from –60 per cent to +4 per cent. There was a decrease in compliance in 5 of the 7 cases with an average decrease of 17 per cent for the entire group.

8. *Lung-Thorax Compliance at the Beginning and End of Intrathoracic Operations.*—A group of 5 patients undergoing intrathoracic surgery was studied to determine if any change in lung-thorax compliance occurs during the operation. The lung-thorax compliance was measured in the anesthetized patient before the operation was started and again at the completion of the operation. The position of the patient and the depth of anesthesia were kept as nearly the same as possible for the two measurements. The measurement at the end of the operation was made with the thoracic incision closed, the lung expanded, and the drainage tube connected to an underwater seal. The results are shown in Table VII. The change in lung-thorax compliance ranged from –44 per cent to +3 per cent. A decrease in compliance occurred during the operation in 4 of the 5 cases with an average decrease of 16 per cent for the entire group at the end of the operation.

TABLE VII. LUNG-THORAX COMPLIANCE AT THE BEGINNING AND END OF INTRATHORACIC SURGERY

CASE NUMBER	COMPLIANCE AT BEGINNING (ML./CM. H_2O)	COMPLIANCE AT END (ML./CM. H_2O)	COMPLIANCE CHANGE (PER CENT)
C_4	31	27	–13
C_{12}	30	31	+3
P_2	47	38	–19
P_3	62	57	–8
P_8	59	33	–44
5 Cases			Average –16

9. *The Range in Lung-Thorax Compliance Occurring During Intrathoracic Operations.*—A group of 13 patients undergoing intrathoracic surgery was studied to determine the range of variation in the lung-thorax compliance occurring during intrathoracic surgery. All of the measurements were made during general anesthesia and under widely varying circumstances. A total of 59 measurements were taken on the 13 patients. The lowest measurement was compared to the highest in each patient and the difference was expressed

TABLE VIII. RANGE IN LUNG-THORAX COMPLIANCE IN INTRATHORACIC OPERATIONS

CASE NUMBER	HIGHEST COMPLIANCE (ML./CM. H_2O)	LOWEST COMPLIANCE (ML./CM. H_2O)	COMPLIANCE CHANGE (PER CENT)
C_2	48	38	–21
C_4	31	25	–19
C_5	80	41	–49
C_7	43	25	–42
C_{10}	78	47	–40
C_{11}	52	39	–25
C_{12}	31	12	–61
P_2	74	38	–49
P_3	62	21	–66
P_5	50	33	–34
P_6	31	20	–35
P_7	57	24	–58
P_8	120	33	–72
13 Cases			Average –44

as the percentage decrease. The results are shown in Table VIII. The percentage decrease ranged from –19 per cent to –72 per cent with an average decrease of 44 per cent.

COMMENTS

Measurement of lung-thorax compliance in the unanesthetized patient presents the problem of obtaining a truly relaxed state. This makes demonstration of significant differences in lung-thorax compliance in unanesthetized patients relatively difficult as was mentioned earlier in the description of the method of measuring compliance. Despite this difficulty, a significant difference was found to occur in this study when patients with pulmonary disease or cardiac disease were compared with normal controls. Factors that would tend to produce decreased lung-thorax compliance in patients with pulmonary disease or cardiac disease are pulmonary fibrosis, the edema and induration of acute inflammation, pulmonary edema of cardiac failure, pulmonary hypertension, pleural effusion, pleural fibrosis, thoracic wall rigidity, and increased intra-abdominal pressure. Ferris, Mead, Whittenberger, and Saxton[10] reported finding a decrease in lung-thorax compliance in patients convalescing from anterior poliomyelitis. Mead, Frank, Lindgren, Gaensler, and Whittenberger[13] studied the compliance of the lungs in a group of patients with rheumatic heart disease in which mitral stenosis was the predominant lesion and found a decrease in lung compliance when compared to a group of normal subjects. Brown, Fry, and Ebert[14] also studied lung compliance in a group of patients with cardiac disease and found a decrease in compliance.

A significant decrease in lung-thorax compliance was found to occur in the interval from the day preceding the intrathoracic operation to the fifth postoperative day. Among the factors, which are probably active in producing this change, are increased edema of the lungs, partial atelectasis due to accumulation of tracheobronchial secretions, irritative effects of gases or anesthetic agents, and involuntary splinting of the thorax due to a painful incision. The lung-thorax compliance was previously measured in a similar manner in a group of patients undergoing operations other than thoracotomy. No significant difference between the preoperative and postoperative compliance was found.[11]

The large decrease in lung-thorax compliance which occurred with the patient under general anesthesia confirms previously reported studies.[11, 15, 16] Nims, Conner, and Comroe[16] have discussed in detail the theoretical consideration involved in this change. They believed the values in the anesthetized state were more likely to be the true values because of the inability of man in the conscious state to completely suppress the tone of the respiratory muscles.

The more nearly linear relationship between pressure and volume in the anesthetized patient permitted the study of relatively small differences in lung-thorax compliance in relatively small groups of patients. The changes in lung-thorax compliance that occurred in the shift from the supine to the lateral position illustrate the importance of two factors in this shift to the lateral position. One factor is the extent of the disease in the uppermost

lung when the patient is in the lateral position and is illustrated in Table IV by Patient P_3 who had a chronic empyema and a markedly thickened pleura which incarcerated bronchiectatic middle and lower lobes and by Patient P_5 who had extensive disease due to bronchogenic carcinoma. In each case, a pronounced decrease in compliance occurred when the shift from the supine to the lateral position was made. A second factor influencing lung-thorax compliance in the shift from supine to lateral position is obesity of the patient, as was previously mentioned.

There was usually an increase in lung-thorax compliance when the chest was opened because of the effect of the increased compliance of the unrestricted lung. When the lung was packed away or retracted, however, a decrease in lung-thorax compliance occurred which usually resulted in a net decrease in compliance when compared to the control measurement. A rather surprisingly slight decrease in compliance occurred during the course of the intrathoracic surgery. A similar decrease was found to occur during operations other than thoracotomy in a group of patients previously studied.[11]

This study indicated that lung-thorax compliance in patients undergoing intrathoracic surgery is influenced by several factors. A rather wide range in compliance can be expected during the course of an operation, and there is variation in compliance between individuals. The effect changes in compliance would have on total volume of pulmonary ventilation during intrathoracic surgery becomes quite apparent. Were fixed inflation pressure used, the elevation of airway pressure necessary to provide an adequate tidal volume might at times be excessive if inflation alone were used to obtain adequate ventilation. Lung-thorax compliance is a factor that merits consideration in providing adequate pulmonary ventilation during general anesthesia for intrathoracic surgery.

SUMMARY

1. A study has been made of lung-thorax compliance in unanesthetized and anesthetized patients with normal and diseased respiratory systems preceding, during, and following intrathoracic surgery. The relation of compliance to adequate pulmonary ventilation is discussed.

2. There was a significant decrease in lung-thorax compliance in 11 unanesthetized patients with cardiac disease and 9 patients with pulmonary disease when compared to 9 normal controls.

3. A significant decrease in lung-thorax compliance occurred in 13 unanesthetized patients between the day preceding intrathoracic surgery and the fifth postoperative day.

4. General anesthesia in 11 patients produced an average decrease of 67 per cent in lung-thorax compliance when compared to the lung-thorax compliance in the unanesthetized state.

5. A variable change in lung-thorax compliance occurred when 10 anesthetized patients were shifted from the supine to the lateral position. A large decrease in compliance occurred in the lateral position in 2 patients with extensive disease in the uppermost lung. A large increase in compliance occurred in an extremely obese patient in the lateral position.

6. An average increase in lung-thorax compliance of 45 per cent occurred in 5 patients when the chest was opened during intrathoracic surgery.

7. An average decrease in lung-thorax compliance of 17 per cent occurred in 7 patients when the lung was packed away or retracted to gain exposure when compared to the control measurement taken before the chest was opened.

8. An average decrease in lung-thorax compliance of 16 per cent occurred during intrathoracic surgery in 5 anesthetized patients when the immediate postoperative measurement was compared to the immediate preoperative measurement.

9. A variation in the individual tested occurred in the lung-thorax compliance of 13 patients during intrathoracic surgery. There was an average decrease of 44 per cent when the minimum and maximum compliance were compared.

10. These findings and their significance are discussed.

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(For Discussion, see page 474.)

INEFFICIENT CARBON DIOXIDE ABSORPTION REQUIRING INCREASED PULMONARY VENTILATION DURING OPERATIONS

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THE occurrence of respiratory acidosis during surgical operations is due to inadequate removal of carbon dioxide from the body.[8] This should not occur if a sufficient volume of ventilation is supplied to remove carbon dioxide as rapidly as it is produced. The absence of pronounced clinical signs complicates the recognition of acidosis. Cyanosis may not occur because the oxygen available in anesthetic mixtures, being several times that of the atmosphere, facilitates adequate oxygenation even in the face of lower ventilatory volumes. Carbon dioxide removal does not enjoy this same advantage. The anesthetic mixture cannot be altered to enhance the removal of carbon dioxide. A normal tension of carbon dioxide (pCO_2) in the arterial blood indicates that the pulmonary ventilation is adequate.

The possibility that a defect in the CO_2 absorption mechanism might be responsible for some of the increase in required ventilation has been suggested previously.[7] Studies in our laboratory revealed incomplete carbon dioxide absorption in the anesthetic circuits in routine use in our hospital.[9] We are reporting here measurements of the effect of this incomplete CO_2 absorption on the ventilatory requirements.

METHODS

Preoperative sedation consisted of barbiturates followed by atropine and morphine or Demerol. Anesthesia was induced with intravenous thiopental sodium, oxygen, and succinylcholine. After the introduction of the endotracheal tube, anesthesia was continued with oxygen and ether. As soon as the tube was in place the gas sampling apparatus was attached to the endotracheal tube (Fig. 1). A closed circle type anesthetic apparatus was used. Ventilation was measured on the expiratory line by a dry test volume displacement gas flow meter. This meter has a flow rate capacity of 2.4 to 70 L. per minute with a resistance of less than 0.5 cm. of water at the higher flow rates. Expired gas was sampled in a chamber containing a spring driven fan (gas mixing chamber, Fig. 1). Pressures within the circuit were read from an aneroid type pressure

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gauge. An oversized (Fig. 2) 3,300 ml. canister was inserted in the inspiratory line to ensure complete removal of carbon dioxide. Concentrations of carbon dioxide in the gases were measured by a Liston Becker infrared absorption carbon dioxide analyzer.

Prior to the start of the operation, a full calibration curve was established using known samples of carbon dioxide in oxygen available in a bank of gas cylinders. The concentrations of carbon dioxide in the cylinders were determined by a micro-Scholander technique.[12] Periodic checks of the gas cylinders by this technique revealed a constant concentration of CO_2 until the cylinders were empty. The concentrations ranged from 1 per cent to 11 per cent. Immediately prior to taking a pertinent reading the machine was recalibrated at the operating table.

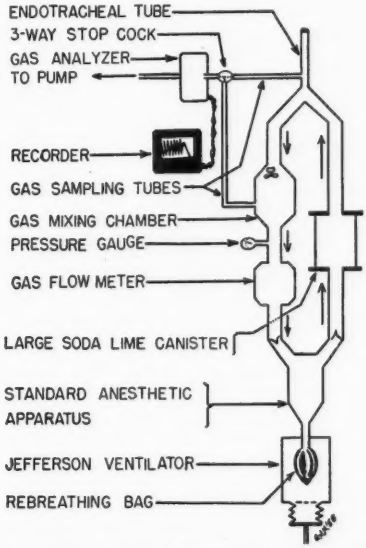

Fig. 1.—Diagram of anesthetic circuit with sampling and measuring devices.

A continuous partial sampling technique with a microcatheter cell was used as described by Collier.[3] The sampling was at a constant rate which was generally 500 ml. per minute. Drift in calibration was avoided by allowing the analyzer to warm up overnight. The analyzer cell was at the head of the patient. A three-way stopcock at the proximal end of the analyzer made it possible to selectively sample from either the end of the endotracheal tube or the mixing chamber. One could thus read the concentration of CO_2 in the inspired air and end expired air, or the mixed expired air (*A*, *B*, and *a* in Fig. 3). A continuous record was made on an Esterline Angus recorder. Visual checks and occasional photographs were made of an expanded tracing on a simultaneously recording oscilloscope.

The patient's lungs were ventilated by a positive-negative pressure apparatus (Jefferson Ventilator). This made it possible to maintain any desired

volume or rate. A Cournand arterial needle was placed in a brachial artery. Observation of the end expiratory reading on the carbon dioxide analyzer was used as an indication of the pCO_2 of the alveolar air. When a steady state existed, with neither CO_2 accumulation nor excessive removal, the end expiratory reading remained constant. The patient was rendered apneic by hyperventilation. If succinylcholine had been used it was discontinued at this point. Pulmonary ventilation was then gradually decreased. The first evidence of voluntary breathing could be readily detected by a change in the oscilloscopic pattern. The concentration of CO_2 in the end expiratory gas at this point was noted. Ventilation was then increased slightly to render the patient apneic,

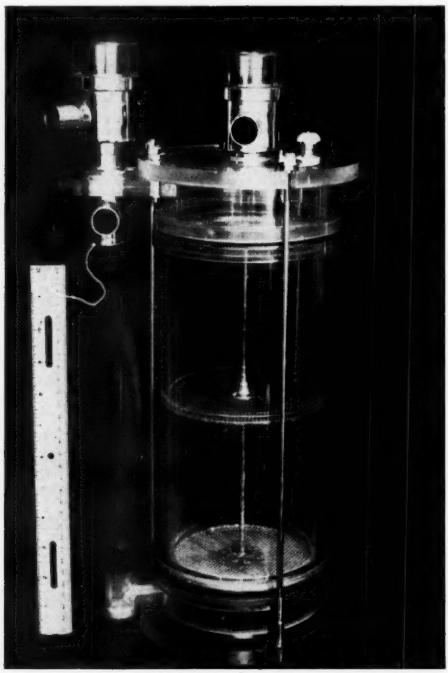

Fig. 2.—Photograph of large, 3,300 ml. canister used to ensure complete removal of carbon dioxide from the gases in the anesthetic circuit. (Designed by Drs. James O. Elam and Elwyn Brown.)

lowering the end expiratory reading slightly. The end expiratory CO_2 concentration was then maintained constantly at this level by adjustment of the volume of ventilation. If desired by the anesthetist, succinylcholine was used after this point. A steady state was considered to be present if the end expiratory reading remained unchanged for ten minutes. This requirement was always met before pertinent measurements were made. The technique then consisted (Fig. 3) of measuring the ventilation while the carbon dioxide concentration of mixed expired gas was determined (*a*); recalibration (*b*); again measuring the ventilation and carbon dioxide concentration of the mixed

expired air. Coincident with the second measurement, the arterial blood sample was drawn. Samples were drawn in oiled syringes containing a small amount of heparin and a drop of mercury to facilitate mixing. Determination of pH and CO_2 content and calculation of arterial pCO_2 were carried out according to methods described previously.[10]

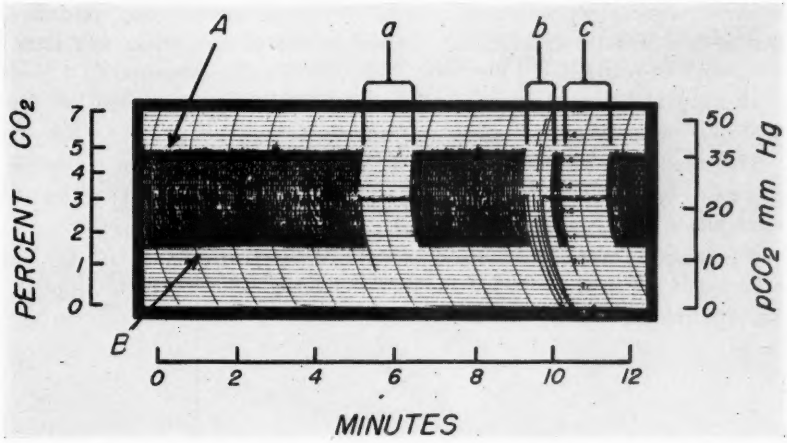

Fig. 3.—Photograph of tracing of the concentration of carbon dioxide in the respired gases. *A* indicates the concentration of carbon dioxide in the end expired gas, and *B* the concentration of carbon dioxide in the inspired gas. During *a*, the concentration of carbon dioxide in the mixed expired gas was measured. The analyzer was recalibrated during *b*, after ten minutes of a steady state. The measurement of *a* was repeated during *c*, the ventilation was measured, and an arterial blood sample drawn.

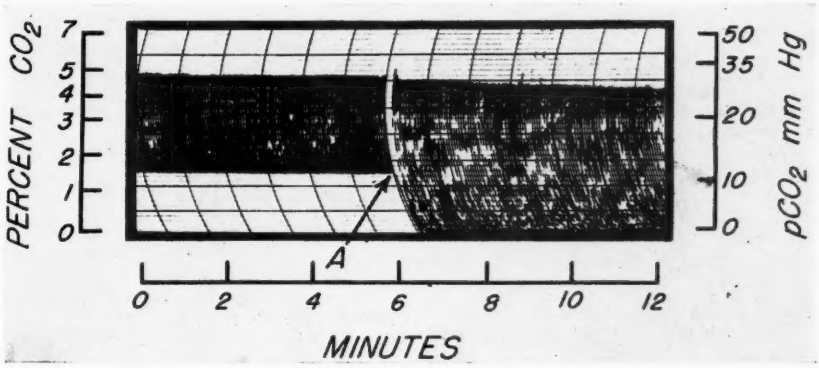

Fig. 4.—Elimination of CO_2 from inspired gas by changing canister. Photograph of tracing of carbon dioxide concentration as in Fig. 3. The large canister (Fig. 2) was placed in the circuit at point *A*.

Following the completion of these preliminary studies the oversized canister was removed from the inspiratory line. The conventional absorption canister in the anesthetic apparatus was then allowed to function. In all instances, the canisters were filled with fresh absorbent. As the carbon dioxide absorption became incomplete it could be noted on the tracing of the sample

taken from the end of the endotracheal tube. The tracing no longer returned to zero during inspiration indicating the presence of carbon dioxide in the inspired air (*A* in Fig. 4). If no changes were made in the ventilation there was a gradual increase in the concentration of carbon dioxide in the end expired gas. In order to maintain the concentration of CO_2 in the end expired air at the previously determined point it was necessary to increase the ventilation. The increase in ventilation was accomplished by increasing the tidal volume (by widening the pressure differential). The duration of inspiration was equal to the duration of expiration. The ventilation and the mixed expired CO_2 concentration were measured periodically. Arterial blood samples were also drawn periodically when the patient was in a steady state.

The minute ventilation, the rate, the concentration of CO_2 in the inspired air, the end expired air and the mixed expired air were measured. From these measurements the alveolar pCO_2 and CO_2 output were calculated.

The alveolar ventilation may be defined as that volume of the total ventilation in which the pCO_2 of the inspired gas equilibrates with the pCO_2 of the arterial blood.

Alveolar ventilation ($\dot{V}_A$) was calculated by the formula:

$$(1) \qquad \dot{V}_A = \frac{\dot{V}_{CO_2}}{F_{A_{CO_2}}}$$

where:

$\dot{V}_A$ = alveolar ventilation.

$\dot{V}_{CO_2}$ = the CO_2 output.

$F_{A_{CO_2}}$ = the concentration of CO_2 in the alveolar air.

Carbon dioxide output ($\dot{V}_{CO_2}$) was calculated as follows:

$$(2) \qquad \dot{V}_{CO_2} = (\dot{V})\ (F_{E_{CO_2}})$$

where:

$\dot{V}$ = minute ventilation.

$F_{E_{CO_2}}$ = concentration of CO_2 in mixed expired air.

Since the pCO_2 of arterial blood is accepted as the more representative value equation (1) becomes:

$$(3) \qquad \dot{V}_A = \frac{\dot{V}_{CO_2}}{\frac{P_{a_{CO_2}}}{P_B - 47}}$$

where:

$P_{a_{CO_2}}$ = the tension of CO_2 in arterial blood.

P_B = prevailing barometric pressure.

47 = correction for water vapor pressure.

This formula would be correct in calculating the alveolar ventilation in patients breathing CO_2 free air but the presence of carbon dioxide in inspired air limits the amount of carbon dioxide which can be removed by a given volume of gas. This must be corrected in the formula as follows:

$$(4) \qquad \dot{V}_A = \frac{\dot{V}\ (F_{E_{CO_2}} - F_{I_{CO_2}})}{\frac{P_{a_{CO_2}}}{P_B - 47} - F_{I_{CO_2}}}$$

where:

$F_{I_{CO_2}}$ = the concentration of CO_2 in the inspired air.

The pCO_2 of alveolar air ($P_{A_{CO_2}}$) was calculated as follows:

(5) $P_{A_{CO_2}} = (F_{A_{CO_2}})$ (PB-47)
Where $F_{A_{CO_2}}$ = the concentration of CO_2 in alveolar air and is considered equal to the concentration of carbon dioxide in the end expired air.

RESULTS

Observations as described above were made during thirteen operations on 12 patients. Every observation during these operations is recorded in Table I, provided that a steady state (constancy of end expired CO_2) had existed for ten minutes and that the tension of carbon dioxide in the arterial blood did not vary more than 4 mm. Hg between observations. The one exception is Case 1 where the lungs were congested in a patient with mitral stenosis and in whom,

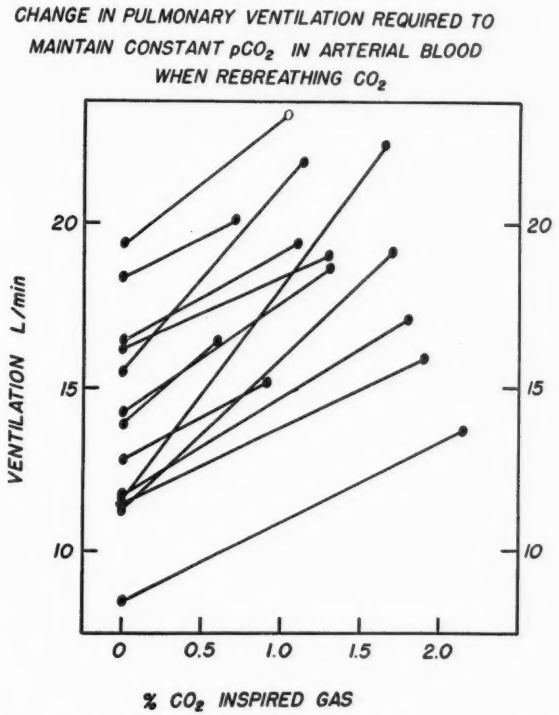

Fig. 5.—In one instance (open circle) it was not possible to compensate for 1.08 per cent carbon dioxide in the inspired gas with a ventilation of 23.4 L. per minute.

despite a total ventilation of 23.4 L., it was impossible to prevent a rise in carbon dioxide tension of 8 mm. Hg when rebreathing approximately one per cent carbon dioxide. In Cases 1 and 2, the thorax was open. In the subsequent cases, the observations were made on patients with a closed thorax because it was found easier to achieve a steady state when there was no possibility of variable compression of the lung. The pressures used during inspiration and expiration are listed in Column 3. In only one instance (Case 10) was it necessary to appreciably increase the rate in order to increase the ventilation.

TABLE I

CASE NUMBER	OPERATION	PRESSURE CM.H_2O	RATE f	TOTAL VENTILATION L./MIN. BTPS $\dot{V}$	TOTAL VENTILATION L./M_2/MIN. BTPS $\dot{V}$	PER CENT CO_2 INSPIRED GAS	PER CENT CO_2 EXPIRED GAS	ALVEOLAR VENTILATION L./MIN. BTPS $\dot{V}_A$	ALVEOLAR VENTILATION L./M_2/MIN. BTPS $\dot{V}_A$	pCO_2 ARTERIAL BLOOD MM. HG Pa_{CO_2}	pCO_2 END EXPIRED GAS MM. HG PA_{CO_2}
1	Mitral valvotomy	+15- 6	18	19.4	11.7	0.00	1.15	4.2	2.5	38	25
		+16- 2	20	23.4	14.1	1.08	2.07	4.4	2.6	46	34
2	Repair of hiatal hernia	+12- 7	12	12.7	7.2	0.00	1.60	3.4	1.9	43	39
		+14- 5	12	15.3	8.7	0.90	2.30	4.7	2.7	39	30
3	Laparotomy	+10- 6	16	15.5	7.9	0.00	1.35	4.0	2.0	37	23
		+10- 6	15	16.8	8.5	0.60	2.00	4.9	2.5	38	28
		+15- 5	15	22.1	11.3	1.13	2.25	6.8	3.4	36	25
4	Abdominal aortic graft	+ 9- 8	18	16.5	9.8	0.00	1.13	2.7	1.6	48	32
		+11- 9	20	19.4	11.5	1.10	1.95	3.0	1.8	46	32
5	Cholecystectomy	+11-10	14	18.4	8.8	0.00	----	--	--	44	30
		+13- 6	13	20.1	9.6	0.70	1.60	3.2	1.5	45	26
6	Excision, rectum	+ 8- 8	16	13.5	8.6	0.00	1.95	5.2	3.3	36	33
		+14- 9	16	18.1	11.6	0.90	2.40	6.3	4.0	37	33
		+17- 9	16	19.0	12.2	1.33	2.76	6.9	4.4	38	34
7	Gastrectomy	+ 8- 5	14	14.2	6.8	0.00	2.05	5.3	2.6	39	34
		+10- 9	14	18.7	9.0	1.30	2.65	6.1	2.9	39	34
8	Thyroidectomy	+ 6- 5	16	11.7	7.4	0.00	2.18	5.5	3.5	34	34
		+ 9- 8	17	17.2	10.9	1.80	3.05	6.8	4.3	36	33
9a	Excision, tumor parotid	+10- 2	16	11.5	7.1	0.00	1.08	3.9	2.4	39	32
		+11- 5	16	15.9	9.8	1.90	3.10	5.7	3.5	38	31
9b	Scalenectomy	+ 8- 6	13	13.9	8.5	0.00	1.55	3.8	2.4	40	28
		+12- 6	13	18.0	11.1	0.60	1.75	4.7	2.9	36	28
10	Colectomy	+ 9- 5	14	11.6	6.7	0.00	1.65	4.6	2.6	30	26
		+10- 4	14	13.9	8.0	1.55	1.90	4.9	2.8	32	27
		+13- 6	20	22.4	12.9	1.65	2.70	9.8	5.6	29	25
11	Mastectomy	+ 7- 5	14	11.4	7.6	0.00	2.00	4.8	3.2	34	31
		+ 9- 8	15	19.2	13.1	1.70	2.65	6.4	4.4	33	31
12	Thyroidectomy	+ 6- 5	14	8.5	5.0	0.00	----	--	--	51	28
		+ 8- 5	14	12.3	7.1	0.80	----	--	--	52	27
		+ 8- 6	14	13.7	8.0	2.15	----	--	--	54	29

Total and alveolar ventilation are expressed in gas volumes at body temperature, prevailing barometric pressure, and saturated with water vapor. The ventilation figures have also been related to body surface area in order to permit comparison between patients. The indicated concentration of carbon dioxide in the expired gas refers to the mixed expired gas and not to the concentration

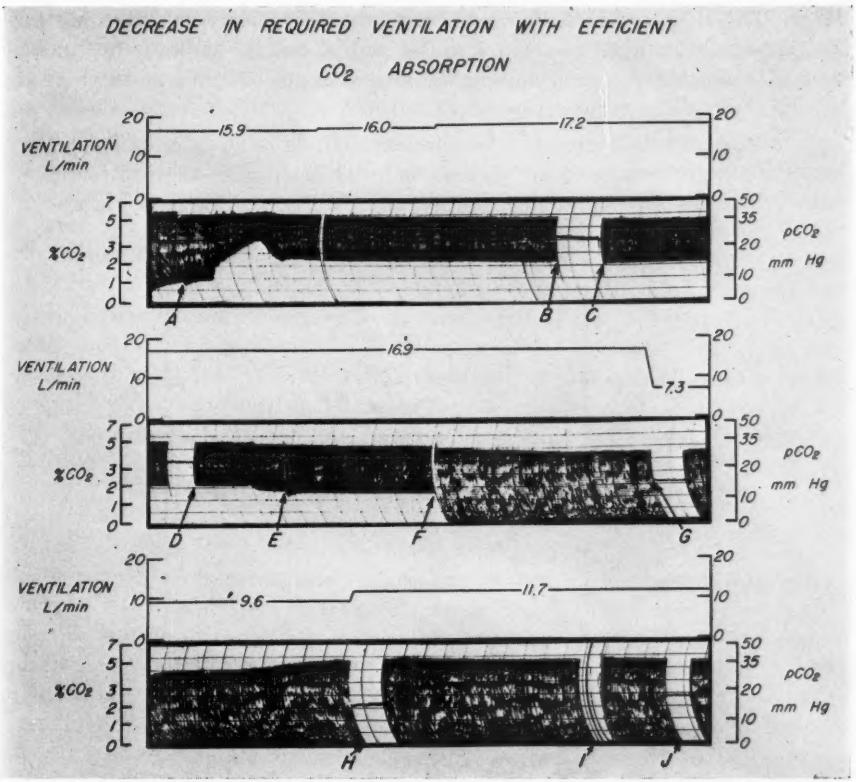

Fig. 6.—Tracing of carbon dioxide concentration. and graph of ventilation, during operation in Case 8. The concentration of carbon dioxide in the inspired gas rose rapidly at *A*. The carbon dioxide in the mixed expired gas was measured from *B* to *C*. A second similar measurement was completed at *D* after a ten-minute steady state. The ventilation was measured at the same time and the carbon dioxide output calculated. Carbon dioxide absorption was obviously incomplete and the patient was rebreathing gas containing approximately 2 per cent carbon dioxide. At *E* the other canister in the anesthetic machine containing "rested" absorbent was switched into the circuit with little effect. At *F*, the large canister (Fig. 2) was substituted for the canister in the anesthetic machine. This immediately resulted in complete absorption and no carbon dioxide in the inspired gas (bottom of tracing) and a reduction in the carbon dioxide of the end expired gas (top of tracing) until the ventilation was decreased at *G*. The carbon dioxide in the end expired gas then rose until point *H*. At *I*, the apparatus was recalibrated and at *J* the carbon dioxide in the mixed expired gas was determined after ten minutes of a steady state.

at the end of expiration. This latter concentration is expressed in millimeters of mercury in the last column of the table. The observations made are listed in chronological order during each operation with the exceptions of Cases 8, 11, and

12. In these 3 patients, the studies made when the patient was not rebreathing carbon dioxide were made toward the end of the operation, but are listed first for the sake of uniformity in the table.

In every instance when the patient was rebreathing carbon dioxide, the measured total pulmonary ventilation had to be increased in order to maintain the tension of carbon dioxide in the arterial blood at the same approximate level. The alveolar ventilation, of course, also had to increase when carbon dioxide was rebreathed to avoid a rise in carbon dioxide tension. In Cases 5 and 12, satisfactory carbon dioxide outputs were not obtained and hence the alveolar ventilation could not be calculated.

The increase in pulmonary ventilation required to maintain an approximately constant tension of carbon dioxide in the arterial blood when rebreathing carbon dioxide is graphically illustrated in Fig. 5. There was a rise in

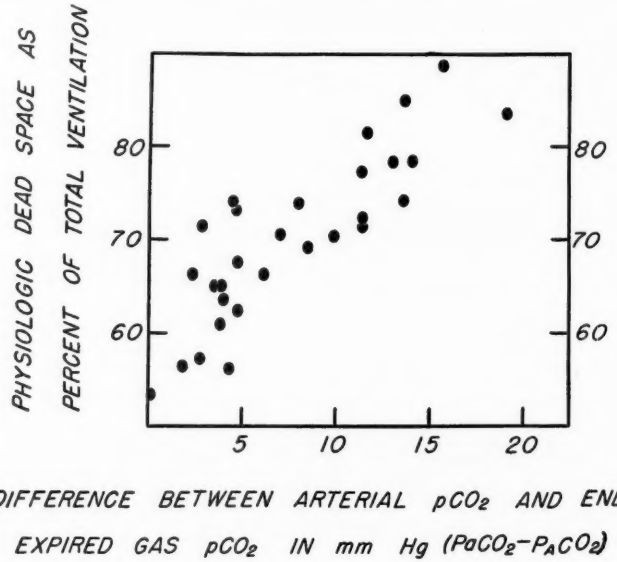

Fig. 7.—Graph illustrating the increasing disparity between the measured tension of carbon dioxide in arterial blood (P_{ACO_2}) and in the end expired gas (P_{ACO_2}) as the physiologic respiratory dead space increases.

every instance, but the rise was not proportionate to the amount of carbon dioxide in the inspired gas. This lack of correlation is to be expected because of differences in pulmonary function and distribution of the respired gases in the lungs. The top line of the graph represents the observations in Case 1 where even with a marked increase in ventilation, the tension of carbon dioxide in the arterial blood rose when rebreathing carbon dioxide.

Fig. 6 illustrated the effects of changes in carbon dioxide absorption and pulmonary ventilation during the course of the operation in Case 8. When

complete absorption of carbon dioxide was achieved by using the large canister, point *"F,"* the ventilation could be reduced from approximately 17 L. per minute to less than 12 L. per minute, maintaining the same tension of carbon dioxide in the arterial blood, for example, 35 mm. Hg.

The disparity between the tension of carbon dioxide in the expired gas at the end of expiration measured by the infrared analyzer and the tension of carbon dioxide in the arterial blood calculated from the carbon dioxide content and pH is apparent. These figures appear in the last two columns of Table I. Here again under the conditions of anesthesia with controlled mechanical ventilation, unequal distribution of the respired gases in the pulmonary alveoli may be largely responsible for the difference in these figures. In our own experience and in that of Collier and his associates[3] with conscious patients, this disparity practically disappears. As would be expected, the disparity increases with increase in the physiologic dead space as illustrated in Fig. 7. In this figure, the physiologic dead space is derived by subtracting the per cent of the total ventilation which is effective (alveolar ventilation) from 100 per cent. Under normal conditions in conscious individuals, the physiologic dead space amounts to approximately 30 per cent of the total ventilation.[4] In the observations reported here under anesthesia with controlled mechanical ventilation, the physiologic dead space varied between 55 and 90 per cent. At 55 per cent, the tension in the arterial blood equalled that in the end expired gas. Between 55 and 65 per cent, the difference amounted to less than 5 mm. Hg.

DISCUSSION

Previous publications from this laboratory and elsewhere have documented the frequency of the occurrence of respiratory acidosis during surgical operations.[2, 6, 7, 8, 13] A method of avoiding such acidosis by the use of a mechanical positive and negative ventilator has been described.[1, 10] The large increase in pulmonary ventilation required to avoid respiratory acidosis has not been adequately explained. A number of factors are undoubtedly contributory. We have found that one of these factors is incomplete absorption of carbon dioxide in two standard models of anesthetic machines in use in our hospital. The incomplete absorption was found to be due to (1) improper channelling of the gases through the anesthetic apparatus, and (2) the use of a widely advertised carbon dioxide absorbent which proved to be far less efficient than U.S.P. soda lime. These findings will be reported in detail elsewhere.[9]

We have reported here the increase in pulmonary ventilation required to prevent an increase in the pCO_2 of arterial blood when the patient rebreathes carbon dioxide in the concentrations produced by these inadequate anesthetic machines. The required increase in pulmonary ventilation under these circumstances is significant, varying between 9 and 93 per cent. It seems likely that our experience with the apparatus and material supplied by national concerns is probably being duplicated in many other hospitals. This assumption could be substantiated by appropriate studies.

SUMMARY

1. Incomplete carbon dioxide absorption was found to occur in two widely used types of anesthetic machines.

2. With incomplete carbon dioxide absorption in a closed rebreathing circuit, the pulmonary ventilation must be considerably increased in order to avoid the accumulation of carbon dioxide and respiratory acidosis.

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DISCUSSION

DR. ETHAN FLAGG BUTLER, Elmira, N. Y.—For many years there has been no comprehensive review of the subject of anesthesia in thoracic surgery. But in the early days of this Association, anesthesia was a very important topic. In 1917, Samuel J. Meltzer was elected the first President. He was an internist whose claim for thoracic recognition lay in his development of intratracheal insufflation, a procedure which added greatly to safety in thoracic work. Willy Meyer emphasized the necessity for differential pressure anesthesia, and at one time hoped that the Association would unanimously go on record that differential pressure must be available before a chest was opened. In 1921, Rudolph Matas gave a most scholarly paper on the subject of anesthesia in thoracic surgery and artificial respiration. Matas' paper was published in *Archives of Surgery* in one of the 1922 volumes. James T. Gwathmey spoke two or more times on anesthesia before this Association; I think the last time was in 1924 when he brought up the subject of ethylene. And then Howard Lilienthal really crystallized the status of anesthesia in thoracic work in his 1925 book, where you will find the statement, "Very few thoracic operations of more than 45 minutes' duration are followed by recovery."

DR. A. E. GAENSLER, Brookline, Mass.—Referring first to the paper presented by Dr. Gordon, I think the importance of a short inspiratory and a long expiratory phase is great. In the majority of patients in whom we are worried about respiratory reserve, there is complicating emphysema or asthma. These patients can find enough time to expire during the long expiratory phase. I would take exception to the use of a negative phase in such patients. Use of such a negative phase implies that we are able to remove the air from the lungs at any rate which we or the pump may choose. In patients with asthma or emphysema who have diffuse respiratory obstruction particularly on expiration, the air will not egress from the lungs at the rate we would like. Under these circumstances the only effect of a negative expiratory phase will be collapse and occlusion of the major airways and complete shut off to the egress of air regardless of the negativity of the pressure.

The second comment concerns Dr. Brownlee's paper: Three basic conditions must be observed for measurement of the compliance of the thorax and lungs, namely, that the thoracic cage is intact, that there is complete muscular paralysis, and that at the time of measurement there is no flow of gas, because if there is flow of gas the force applied obviously would also be a measure of resistance to flow and not only of compliance. Probably time was too short for Dr. Brownlee to clarify these points. At any rate some interesting observations have been made recently at the Department of Physiology of the Harvard School of Public Health by measuring compliance of the lungs alone with an intraesophageal balloon. The compliance diminishes rapidly during the course of anesthesia without respiratory assistance. Concomitantly with this, there is also progressive diminution of the capacity of the lungs to transfer oxygen, the so-called oxygen diffusion capacity. This process is instantly reversible by manual inflation. Since we know that under these circumstances the anatomy and structure of the lungs, the amount of available lung tissue, the degree of expansion, and the pulmonary pathologic process, if any, do not change and we find that the compliance and diffusion capacity do change, we can draw only one conclusion; the individual must be breathing with a progressively smaller lung. That he is breathing with less and less lung is probably due to temporary closure of certain alveoli and there must be reversible atelectasis of certain regions of the lung. The lung actually does become smaller. In the conscious man at rest this process is probably reversed by occasional sighs and during anesthesia it is reversed by intermittent application of positive pressure.

Referring last to Dr. Nealon's paper on CO_2 absorbers, the removal of carbon dioxide from closed rebreathing systems has been a vexing problem to anesthetists, respiratory physiologists, and endocrinologists for at least thirty years. It led to the controversy between Krogh and Knipping in the 1920's as to what kind of "scrubber" should be used. The problem can be stated simply: If an instrument is used which effectively removes all expired CO_2 then the resistance to breathing becomes so great as to be intolerable to the patient. Among people who build spirometers and basal metabolism apparatus, three types of systems were evolved. In one, the expired air is bubbled through concentrated sodium hydroxide solution which removes all CO_2 but causes so much resistance that a circulating fan must be used to prevent severe resistance breathing. In another, an open circuit is used where the patient breathes room air through one valve and breathes out into a collecting bag, the content of which is subsequently analyzed. The third solution is the compromise which we use today, the soda-lime canister. We all realize that it does offer moderate resistance to breathing and that it does not remove all expired CO_2. The use of shaped pellets (Baralyme) is again a compromise. It reduces efficiency of CO_2 removal but at the same time decreases resistance breathing.

During anesthesia there are a great many factors which cause CO_2 retention. The part played by the soda-lime canister alone can be explored best in a fully conscious normal subject.

(Slide) This shows a tracing obtained under these circumstances with inspired CO_2 tensions at the bottom and end-tidal CO_2 tensions on top, plotted against time. A normal volunteer breathes in a closed circuit with a conventional one-pound soda-lime canister. The rate and depth of ventilation were chosen by the subject without instructions and kept him

comfortable. This conscious patient could adapt his alveolar ventilation to the inspired CO_2. Therefore, the end expiratory CO_2 remained at 6 per cent for 45 minutes. However, during this time alveolar ventilation increased from about 6 L. a minute to about 20 L. a minute while the inspired CO_2 increased from 0.3 per cent to 2.5 per cent. Finally, at the end of 105 minutes this man could no longer compensate for an inspired CO_2 concentration of 5.8 per cent by increase in ventilation and even this conscious subject began to show respiratory acidosis with an increase of end expiratory CO_2 to 7.8 per cent.

(Slide) Here are plotted the inspired CO_2 rising from 0.3 per cent up to 5.8 per cent at 105 minutes and the alveolar ventilation from 6 L. to 28 L. per minute. This situation would of course have been much worse in an anesthetized patient because he cannot increase the tidal volume as this individual did but must increase alveolar ventilation by the much less efficient means of increase in respiratory rate.

This one-pound canister is thus a compromise and the most important factor in this compromise is time. I think if the ordinary canister is changed faithfully every 15 minutes, then the problem is probably not too great. If the size of the canister and the type of the soda-lime are changed so as to absorb efficiently all CO_2 for long periods, then we would have to give some thought to the fact that respiratory resistance is increased, and we are then committed to some means of ventilating these patients artificially during anesthesia.

DR. HERBERT C. MAIER, New York, N. Y.—This has been a most valuable symposium and I would like to compliment those who presented papers. During the past year we have used a Jefferson ventilator with its positive and negative phase during anesthesia for lung surgery, and I would like to show you 2 illustrative cases in which we had previously hesitated to operate without the aid of positive-negative ventilation.

(Slide) In this patient on the left side there is a large empyema with pleural calcification, and on the right side a nonfunctioning lung with a fixed diaphragm. Obviously this patient's respiratory reserve was extremely low. The only portion of her chest that could move, in other words, the only portion of the bellows mechanism that was effective was the left diaphragm. The first time we took her to the operating room and employed ordinary ventilation with manual compression of the anesthesia bag, there was rapid deterioration of the circulation and we were unable to obtain any appreciable depth of anesthesia due to lack of adequate ventilation, and there was obvious congestion of the cervical veins. Later this patient was operated upon with the help of the Jefferson ventilator, which permitted adequate ventilation of the left lung and better motion of the diaphragm, without circulatory impairment.

(Slide) This is the postoperative film after decortication showing a very satisfactory re-expansion of the lung.

(Slide) This is a film of a patient with severe kyphoscoliosis who had collapse of the lung on one side due to progressive distention of pulmonary cysts, with only a little expanded lung tissue remaining in the hilar area. This patient was in obvious severe respiratory distress, but through an anterior thoracotomy approach, again with the aid of the Jefferson ventilator at the second attempt, we were able to remove the cysts successfully and get lung expansion.

In conclusion, I would like to emphasize that both these patients were able to return to work within two months following operation because the main hurdle was the proper management of their ventilation during an operation which was designed to improve their critically reduced pulmonary function.

DR. JEROME R. HEAD, Chicago, Ill.—The presentation of these interesting and excellent papers before this Association seems to me important and appropriate. However much the anesthesiologists have tried to argue us out of the contention, the responsibility for the anesthesia lies with the surgeon, and for the surgeon to pass it entirely to the anesthesiologist is against Hippocratic principles and against the principles of modern law. The findings presented in these papers also seem encouraging. It means that what we had almost come to accept as a fated and unavoidable accident is becoming an understandable

phenomenon and a preventable phenomenon. Among all primitive peoples, when anything is not understood and is potentially disastrous, it is attributed to evil spirits, and I would confess that my attitude toward cardiac arrest has been heretofore largely on that basis. One of the evil spirits has been the anesthesiologist but, more specifically and less facetiously, for a long time I placed my faith in ether. As a young man I went into the operating room and was given a can of ether and a mask and told to put people to sleep. They all lived, which was very surprising to me, and I attributed it entirely to the fact that you could not kill people with ether. But I found out, over a period of years, that I had had three cardiac arrests under pure ether anesthesia, all of them during induction. I am sure now that this was because of inadequate relaxation and of multiple attempts to insert an intratracheal tube. I was finally convinced that a long difficult induction with multiple attempts to insert a tube was bad. I should have said also that one of my evil spirits was curare; I turned to Pentothal and nitrous oxide and to controlled respiration, and I put my faith in that, as one would put his faith in a god or a dance or whatever you have. I got along very well with that until I realized that controlled respiration was of two kinds, either manual or mechanical. Recently I had a case of cardiac arrest due, I feel sure, to the fact that the anesthesiologist became so interested in watching the resident put a catheter into a vein in the leg that he forgot to pump the bag. That is a human error and, as a result of it, I have gone to mechanical respiration and to hyperventilation. Hyperventilation may have certain drawbacks but they are much less than those of underventilation. Therefore, at the present time, as soon as I make the incision I begin to say—"The blood is black, come on, get going, the blood is black." I do that at intervals all through the operation and so far it has worked. I have not had a cardiac arrest for a year.

These papers are very interesting and very important but they do not show what happens during cardiac arrest. I feel that every anesthetic agent at the present time should be considered experimental, that any anesthesiologist who is not checking himself and being checked by blood oxygen readings, by CO_2 analyses, and by the running electrocardiogram, is not being a good anesthesiologist. The only way in which we will learn exactly what happens, exactly what causes cardiac arrest, is to have such data on a group of patients who have suffered cardiac arrest.

DR. PAUL NEMIR, JR., Philadelphia, Pa.—I too wish to congratulate the authors of these excellent papers. We have been interested in the problem of respiratory acidosis and I wish to comment briefly on some work being done in our department by Dr. Hrant Stone and Dr. David Seligson on the problem of carbon dioxide retention. Evidence is available which indicates that other buffer systems exist in the body to absorb high concentrations of retained carbon dioxide. These buffer systems are present in muscle masses and bone and are capable of absorbing many times the amount of carbon dioxide that is handled by the blood. During surgical procedures, particularly thoracic surgical procedures, when carbon dioxide retention occurs and the arterial pCO_2 rises, serious changes in other blood constituents usually will not occur unless the pCO_2 exceeds values of 90 to 100. However, if it increases above this level, the serum potassium rises. In the presence of normal kidney function, potassium excretion maintains a normal blood level of this constituent. However, during surgery many factors such as hypotension, dehydration, and shock depress renal function and thus cause a hyperkalemia. In addition, many anesthetic agents and drugs used during anesthesia produce a decreased urine flow, due to stimulation of the antidiuretic hormone of the posterior pituitary. The presence of pre-existing renal disease may further prevent the kidneys from effectively eliminating potassium from the blood. By controlled occlusion of the ureters it has been possible to detect these changes in the presence of acidosis of sufficient magnitude. In terms of time, the changes in potassium level were significant in one and one-half hours which is a short time in terms of the present duration of many surgical procedures. It is conceivable that cardiac arrest which occurs, following certain types of surgery without apparent cause, actually represents a hyperkalemic death secondary to severe respiratory acidosis and impaired renal function.

DR. GEORGE H. A. CLOWES, JR., Cleveland, Ohio.—This has been an interesting session. I agree with Dr. Head and Dr. Nemir that it is all very well to say that carbon dioxide rises or that respiratory exchange is inadequate. What we need to know is the effects of these occurrences upon the patient, and more particularly upon his heart, circulation, and nervous system.

In an attempt to understand more of the mechanisms entering into the production of circulatory failure during surgery we have been trying to sort out the effects of the various components which enter into cardiac arrest: hypercapnia, hypoxia, anesthetic agents, and hypotension. This has been approached both from hemodynamic and biochemical standpoints. In essence, pure carbon dioxide accumulation of the degree described today produces very little effect if other factors remain equal. It is only when the respiratory mixture contains more than 15 per cent CO_2 that we begin to see any changes of note. Mixtures containing more than 30 per cent are required to produce significant brain depression or shifts in serum potassium in man.

Hypoxia is a different matter. Little effect is produced on any of the systems except a discharge of the adreno-sympathetic mechanism until the arterial oxygen level falls below a "critical level" of approximately 4 volumes per cent. At this time events progress rapidly. Recent studies in our laboratory show that cardiac output falls while peripheral resistance and venous pressure rise. Thus, this represents a failure of the cardiac muscle and an inability to continue its normal pumping action.

There are shifts in serum electrolytes which accompany both hypoxia and hypercapnia. Those relating to potassium have been described by Seeley, ourselves, and others. The effects on calcium and magnesium are at times dramatic, yet we cannot understand them or classify them at present.

As for anesthetic agents and their effects on the homeostatic mechanisms I have been discussing, I have less firsthand knowledge.

I hoped that Dr. Beecher and some of the other gentlemen who spoke this afternoon would say a little bit more about these various things we are trying to prevent. At the present time, anesthesia remains an art regardless of the scientific information we may have concerning it. With the same amount of knowledge and equipment one man will be able to avoid too much anesthetic agent and maintain a good patient, whereas another man will not.

DR. N. K. JENSEN, Minneapolis, Minn.—As a thoracic surgeon interested in this problem for the last ten years I was delighted to hear this fine series of papers. I think we are all very much in the position of gradually emerging from the era, Dr. Head described so adequately, of mystery and magic. We have been flying by the seat of our pants, and we are gradually now gathering data on the atmosphere we operate in and are ready to start flying by instrumentation, which is very much safer. Dr. Stead and Dr. Martin and I have studied this problem for about ten years and we have discovered that if the recording equipment is turned away from the anesthesiologist he has no idea where he is. If it is where he can watch it he keeps things well in balance. If he knows the CO_2 content in the expired air and the oxygen saturation he keeps things in balance, but by guess he guesses very poorly.

This equipment is available and can be used. Good infrared CO_2 analyzers are available. Good oxygen content equipment is available, and it should be incorporated in the anesthesia apparatus today. I don't think any of us want to fly home from this meeting in the "Spirit of St. Louis," with a watch hanging for a gravity meter on the dashboard—you just cannot fly safely that way. I do not think you can give decent anesthesia with the equipment we have at the present time. I am sure the equipment can be made available, and I think we should encourage anesthesiologists and maufacturers to make it so.

One other point was well made by Dr. Papper; the hazard of the period of intubation. When the period of intubation starts, somebody should start holding his breath in that room, and if the patient is not intubated and being ventilated by the time the observer must breathe, intubation should be abandoned and the patient again well ventilated before

a new effort is made. The average individual, by measurement, the average healthy interne, can hold his breath for about one minute and in that time his arterial pH drops from 7.4 to 7.3; at 7.25 he is unconscious and the CO_2 retained is a potent anesthetic agent. Likewise, in the recovery period when the anesthesiologist says, "I don't know why this old fellow doesn't wake up; I only used 400 mg. of Pentothal"—that man has been anesthetized probably for the last two hours on carbon dioxide and if you run a pH on him you will be amazed. It will be about 7.1; he will die at about 6.9. You may have to take this patient back to a gas machine and ventilate him for awhile to eliminate enough CO_2 to bring the pH to physiologic levels before he will wake up. The confusion that occurs between the anesthesiologist, carbon dioxide, and the anesthetic agent is one of the real problems in the postintratracheal phase. Unless the carbon dioxide is eliminated sufficiently, spontaneous ventilation is not deep enough to clear the remainder from the blood. Reintubation with further artificial ventilation is essential until the anesthetic effects of respiratory acidosis are eliminated. Without constant measurement of either CO_2 content of alveolar air or arterial pH it is impossible to determine if the continuing anesthesia is due to anesthetic agent or retained CO_2. Proper diagnosis precedes proper treatment.

DR. RICHARD M. PETERS, Chapel Hill, N. C.—In the discussion of the change in compliance in patients under anesthesia, I think it is important to point out that an increase in the concentration of CO_2 in the alveoli causes bronchoconstriction which is real and can make a lung completely unable to deflate passively. This is also true with hypoxia and it may well be that one of the things which changes the compliance in these animals is a loss of pulmonary volume due to increasing portions of the lung being shut off during periods of bronchoconstriction associated with anoxia or hypercapnia. If compliance and airway resistance are measured simultaneously, there is a much greater rise in bronchial resistance with accumulated CO_2 or anoxia than there is a change in compliance. If a patient becomes hypercapnic or anoxic, it will be much harder to achieve good ventilation because of the bronchoconstriction which occurs with these two phenomena. Fortunately, this is a vagal reflex and can be reversed by atropine, and if a patient cannot be ventilated for these reasons, it may well be that the use of large doses of atropine will relieve the bronchospasm so that increased ventilation can be done feasibly to correct hypercapnia.

DR. FRANK F. ALLBRITTEN, JR., Kansas City, Kan.—Dr. Peters mentioned the increased concentration of CO_2 affecting compliance. The patients that were reported on were hyperventilated preceding the measurement of the compliance to the point of apnea. I think the measurements given have no relationship to retained carbon dioxide.

I would like again to stress that at the present time it seems the volume of ventilation is directly proportional to the effective ventilation, and if there is merit in a vacuum phase for deflation of the lung in ventilation, it probably is that of increasing the volume of ventilation within the pressure ranges compatible with the safety of the patient.

The absorption of carbon dioxide discussed by Dr. Nealon is an additional important factor. The demonstration that ventilatory volume could be significantly decreased and still maintain an adequately effective ventilation explains, in part, the increased total volume of ventilation required by anesthetized patients. We think that lung compliance also plays a part. These are two factors, then, which may play a part in the increased volume of ventilation necessary to maintain adequate effective ventilation in anesthetized patients. I suspect that other factors will soon be evident.

DR. JOHN H. GIBBON, JR., Philadelphia, Pa.—I too have found all these papers very interesting. I should like to make just a couple of comments; one, with regard to the paper of Drs. Gordon and Fyre concerning the use of the negative phase in the open chest. Obviously in the vast majority of patients it is not necessary to use a negative phase in the open chest. However, I would like to heartily endorse Dr. Maier's remarks. In several patients with marked emphysema we have had to discontinue open thoracic operations when positive pressure ventilation alone was used. When a negative phase was added, these same patients were adequately ventilated and the open thoracic operations

were successfully completed. Adding the negative phase eliminated the distended lung obscuring the operative field. Despite what Dr. Gaensler said about the theoretical aspects, practically it works; and there are cases in which you will occasionally need a negative phase with an open chest.

With regard to what Dr. Gaensler reported about a widely used carbon dioxide absorbent, this is what Dr. Nealon referred to. We found this absorbent rather worthless. U.S.P. soda-lime was infinitely better. We should have given credit, on the slide illustrating the large canister, to Dr. E. S. Brown who devised it. I might add that this canister, filled with ordinary U.S.P. soda-lime, has been used in prolonged operations three or four hours a day for as long as two weeks without changing the soda-lime and with efficient carbon dioxide, absorption.

Finally, I regard the timing as relatively unimportant. Whether you use an equal duration of inflation and deflation, or a deflation of twice the duration of inflation, or 30 per cent of the respiratory cycle for inflation and 70 per cent for deflation, we still believe that the more important factor is the mean pressure exerted during the respiratory cycle. Perhaps, as Gordon and Fyre believe, the timing is of some importance, but I do not think that you can arrive at that conclusion merely by determination of the blood pressure. We have tried in normal healthy young people with an intact thorax, to reduce the blood pressure by employing a high positive pressure during inflation, omitting the negative pressure during deflation, and have been unable to affect the blood pressure at all. Whereas, in elderly weak patients with hypovolemia the blood pressure will drop to shock levels under these circumstances.

AORTIC VALVULOTOMY UNDER DIRECT VISION DURING HYPOTHERMIA

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INTRODUCTION

EVEN optimistic surgeons cannot hide a certain disappointment with current operations for aortic stenosis. Many less enthusiastic and perhaps less voluble practitioners have never tried these operations, or because of failures, abandoned them. There are at least two important reasons why surgery for aortic stenosis is unsatisfactory. First, and doubtless more important, the aortic valve cusps are usually severely damaged—not just adherent to one another—by the time symptoms occur. In most cases, the valves are calcified producing an almost complete loss of flexibility and because of this a completely satisfactory repair may be impossible unless the valve is actually taken out and replaced with a new one. The second important cause for surgical failure is easier to remedy. It is a failure resulting from use of a closed operative technique in contrast to an open one. Currently employed blind operations may fail to achieve even the modest objective of opening the fused commissures accurately and widely. Often only one of the three major commissures is opened, although the body of a cusp may be torn in addition, thus producing insufficiency.

If, short of complete valve replacement, accurate separation of the adherent cusps is the best operation, this will probably have to be accomplished under direct vision. It is becoming clear that a number of cardiac defects such as atrial septal defects,[9, 17] pulmonary stenosis,[18] ventricular septal defects,[5, 12] as well as rarer defects like tri-atrial heart, total anomalous pulmonary venous drainage,[11] and aortic septal defects[15] can be repaired better under direct vision than with blind techniques or only under direct vision; perhaps aortic stenosis should be added to this group.

With this idea in mind, we pursued the problem experimentally and after satisfying ourselves that direct operations on the aortic valve were feasible, we have used the method in a few clinical cases.[10] Hypothermia has been employed

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and the technique, in general, is much like the one that Swan and his associates[18] have recommended for correcting pulmonary stenosis under direct vision.

EXPERIMENTAL STUDIES

Devising a safe technique for exposing the aortic valve in dogs was not a particularly difficult project but we did have to learn how to avoid air embolism. In addition to working out an operation, we tried to determine how much air could be left, without damage, in the left heart or aorta. The details of these experiments will be published elsewhere,[3] but the important findings may be summarized here.

Air in various amounts was injected into the left atrium, left ventricle, ascending aorta, carotid arteries, and descending aorta. We found that 0.5 c.c., or more, per kilogram of body weight was fatal if injected into the left atrium or ventricle without resuscitative measures, while one to 2 c.c. per kilogram of body weight could be tolerated in the ascending aorta or the carotid arteries in over one half the dogs. Even larger amounts (up to 7 c.c. per kilogram) could be injected into the descending aorta. The cause of death, when air was injected into the left atrium or ventricle, was ventricular fibrillation or standstill secondary to coronary air embolism. If resuscitative measures were attempted with massage and electrical defibrillation, as they were in some of the experiments, they were usually successful. These findings concerning the injection of air in the left heart are in general agreement with the work of Geoghegan and Lam,[6] although we were able to inject more air into the carotid arteries than they could, without central nervous system damage. The important conclusion from these experiments was that small amounts of air could be tolerated even in the left heart, if resuscitative measures were used, and that somewhat larger amounts in the aorta caused no damage. Thus, as far as air embolism is concerned, there is a small but vital margin for error.

Next, in order to stay within this margin for error, we tried various techniques experimentally for eliminating air from the left heart at the completion of an open, aortic valve exposure through the ascending aorta. In all of these experiments, the heart would be removed after completion of the open operation without permitting the circulation to restart. The specimen was submerged in water and a careful search was then made for any air remaining in the chambers or in the coronary arteries. To prevent the escape of air into the systemic circulation during these experiments, a clamp was left on the arch of the aorta even after the aortotomy in the ascending aorta had been closed. All of the vessels were occluded with clamps as the specimen was removed. These experiments showed that it was possible to prevent air embolism by carefully washing out the left heart before closing the aorta. The best technique, which will be described in the next section, has been applied to our clinical cases. As the most important feature of this technique, the aortotomy remained open until several heartbeats of blood and irrigating fluid had pumped out through it. It was then closed with a clamp while blood was pumping out.

Finally, a number of experimental operations were done in which survival was the objective. In 17 dogs, the valve was simply exposed or some direct

operative procedure, such as suturing two of the cusps together, was attempted on the aortic valve. Only one of these animals died during the operation, although all of those that had stenosis or insufficiency produced by the operation died a week or more following surgery.

From the experimental work, we had learned enough to proceed to clinical cases. The experiments showed that though a small amount of air was tolerable in the systemic circulation, it could be avoided by proper technique. Moreover, in dogs, open operations could be done on the aortic valve during hypothermia with a high rate of success.

CLINICAL EXPERIENCE

Unfortunately, our experience with this operation has been small to date. Perhaps this has been due to two unrelated causes. First, as a result of their disappointment with previous operations for aortic stenosis, our medical colleagues have been slow to send new cases on to us. Second, and in contrast, our surgical colleagues who do find cases have, due to their enthusiasm for the logic of the open operation, preferred to do the operation themselves. In any case, despite our small experience, we have developed a satisfactory technique which is described below and illustrated in Figs. 1 through 5.

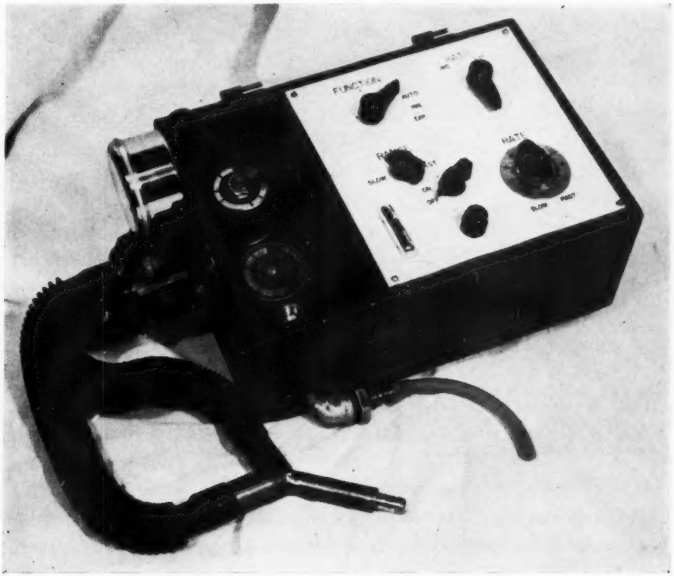


Fig. 1.—The electronically controlled respirator used for most of the animal experiments as well as for the patients. A capacitance-resistance timing circuit controls two solenoid valves. While the expiratory valve is open the inspiratory valve is closed and vice versa.

Technique.—

The procedure for cooling and rewarming is essentially the same as that which we have described previously for other open heart operations.[8, 11] After

anesthetic induction with Pentothal and a curare-type drug and intratracheal intubation, the patient is attached to an automatic respirator. This respirator consists of inspiratory and expiratory solenoid valves which are controlled by an electronic timing circuit (Fig. 1). It employs an open system rather than the more common circle absorption system. The respirator is set at a rate of 13 to 14 per minute and this rate is maintained. Pressure during inspiration rises to about 20 mm. of mercury and the minute respiratory volume is usually 12 to 15 L. for adults. A mixture of 5 per cent carbon dioxide in oxygen is given

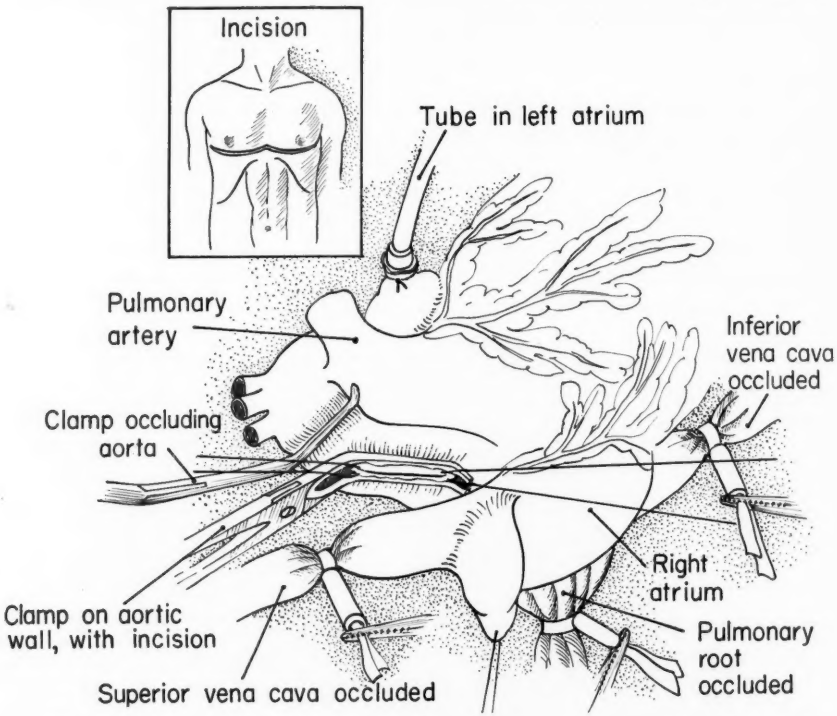


Fig. 2.—The inset shows the position of the chest incision. The remainder of the figure, as well as Figs. 3 through 5, is oriented with the patient's head to your left. Preparations have been completed and the aorta is about to be entered by opening the Beck clamp. There is a tube in the left atrium, and the venae cavae, pulmonary roots, and the aorta, distal to the aortotomy, have all been occluded.

from the beginning of cooling until late in the rewarming period. The use of such a mixture prevents the respiratory alkalosis which occurs if oxygen alone is used with this respiratory system and, with the automatic respirator, rapid changes in blood pH, which are apt to occur with a manual respiratory system, are avoided.

Refrigerating blankets at a temperature of about –4° C. are used for cooling. Surgery is started when the body temperature falls to 30° to 31° C. but the temperature continues to fall, reaching a low point of 28° to 29° C. This low point is slightly higher than we used earlier. The electrocardiograph tracing

is followed continuously on an oscilloscope and blood pH determinations are taken occasionally throughout the procedure. An intra-arterial needle or cannula is used for continuous blood pressure determination.

Fig. 2 illustrates the chest incision. The sternum is divided transversely to allow entry into both pleural cavities through the third interspaces. Loops of tape are placed around both lung roots and then with the pericardium opened widely, tapes are placed around both venae cavae. A small catheter is inserted into the left atrium through the atrial appendage in order to wash air out of the left heart at the end of the open operation.

After infiltrating the tissues around the base of the aorta with procaine, the ascending aorta is cleared. Fat and adventitial tissue are removed proximally, while the right atrial appendage is retracted, far enough to expose the origin of the right coronary artery. Distally, the ascending aorta is freed from the pulmonary artery so that it may be occluded separately. Fine stay sutures (No. 5-0 silk) are placed in the ascending aorta to mark each end of the aortotomy and a Beck clamp (Potts' principle)* is closed beneath the stay sutures to separate a generous lip of the ascending aorta. This clamp appears to be identical to the one described by Clowes[4] which he has employed for the same purpose. As a final step in preparation, the aortotomy incision is made in the lip of aorta held by the Beck clamp (Fig. 2). In this way, no time will be spent in making an incision once the inflow has been occluded.

The steps that are followed after occlusion of the cardiac inflow must be carried out efficiently and without confusion. We have employed a check list enumerating each task in proper order and this list is finally reviewed just before occluding the cardiac inflow. It might be better to have an assistant call off each item on the list as the open operation proceeds. Directly after occluding both venae cavae the respirator is turned off and the loops around both pulmonary roots are tightened in order to occlude the pulmonary veins. After a few heartbeats, a Satinsky clamp is used to occlude the ascending aorta just proximal to the innominate artery and then the aorta is opened by simply removing the Beck clamp. Blood still in the aorta is evacuated by suction to expose the aortic valve (Fig. 3). Following a careful inspection to identify the commissures, each commissure is opened out to the aortic wall. For this we use a knife and a heavy Mayo scissors. We have not tried to remove the calcium from a calcified valve cusp, for a study of pathologic specimens will show that this is impossible without partially destroying the valve, thus producing an insufficiency. After the commissures have been opened satisfactorily, a finger may be passed down into the left ventricle to check the size of the orifice.

Now, in order to close the aorta without leaving air in the left heart the following important tasks are carried out in sequence. The venae cavae and pulmonary roots are released. (We have occluded the pulmonary roots as well as the venae cavae assuming that some blood would thus be dammed up in the lungs to flow out suddenly into the left atrium at this time and thereby help wash out the air.) The fine sutures at either end of the aortic wound are

*Manufactured by B. Richter, 843 Duane Street, Glen Ellyn, Illinois.

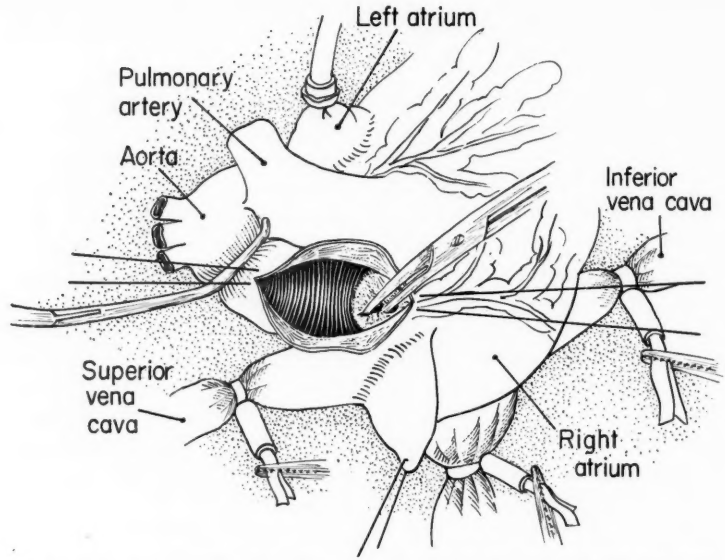


Fig. 3.—With the aorta opened the stenosed aortic valve is exposed and the fused cusps are being separated with a scissors.

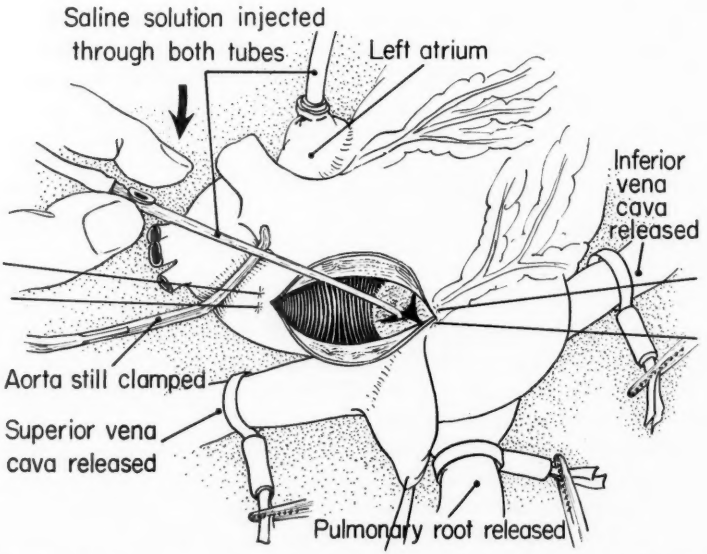


Fig. 4.—In order to evacuate the air in the left heart, blood flow has been restarted by releasing both the pulmonary roots and the venae cavae. In addition, the left heart is flooded with saline solution injected by way of the atrial catheter and through a tube passing down past the aortic valve into the ventricle. The distal aortic clamp is still closed.

elevated and the Beck clamp is placed behind them, ready to close the wound. As this is being done, saline solution is injected under pressure through the catheter in the left atrium, and a small metal tube is passed down through the aortotomy, the aortic valve, and into the left ventricle, to inject more saline solution into the air-filled left heart (Fig. 4). Within a few moments a large gush of blood, saline solution, and air comes out through the aortic incision, and when three or four satisfactory heartbeats have each pumped out air-free fluid, the aortic incision is closed with the Beck clamp and the distal aortic clamp is released. The respirator is then restarted. To keep the field clear for accurate closure of the aortic wound, two suction tips are employed. Once circulation has been resumed, the aortic wound is sutured distal to the clamp with a continuous stitch of No. 5-0 silk (Fig. 5). In the first patient, the mitral valve was explored from the right in the manner described by Bailey,[2] after the aorta had been closed.

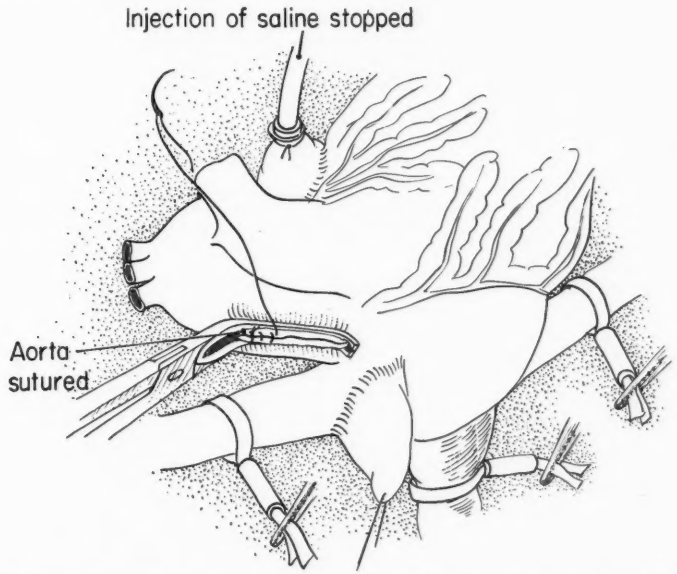
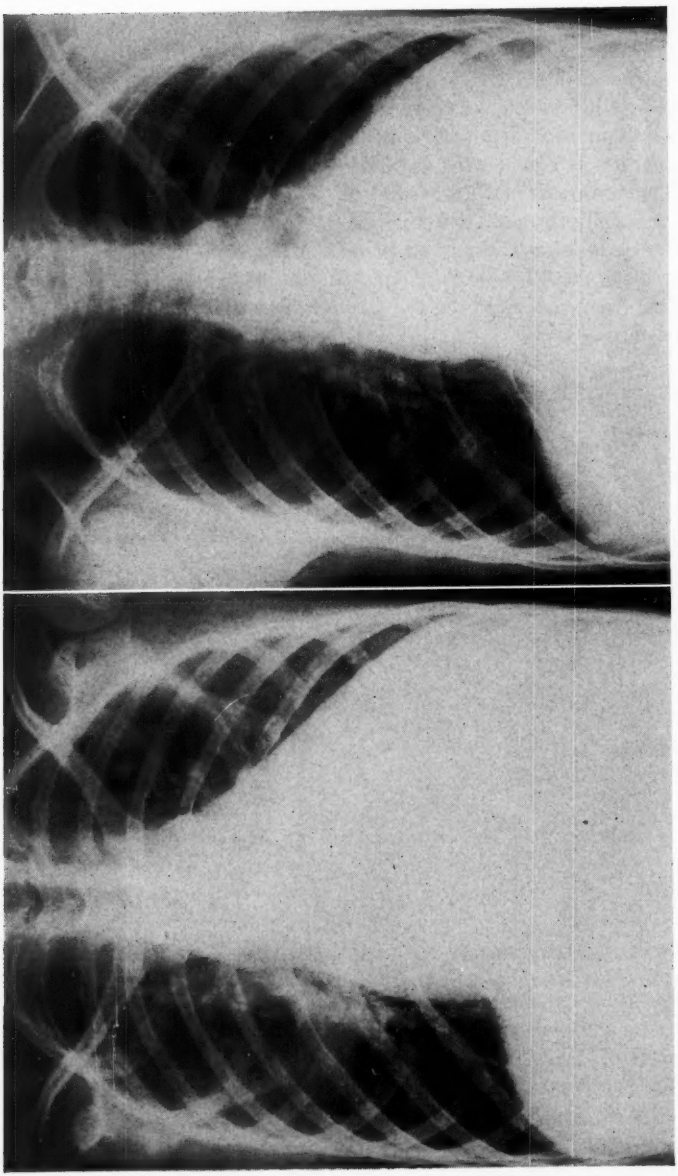


Fig. 5.—With circulation resumed, the aortic wound is sutured over the Beck clamp.

The operation is completed by placing chest catheters in both pleural cavities, closing the pericardium loosely, and repairing the chest wound. Three double strands of heavy, twisted, stainless steel wire hold the divided sternum but pericostal sutures of heavy catgut on either side also help to strengthen this repair.

Rewarming is commenced during the thoracotomy by pumping a warm solution through the blankets which remain under the patient and around the lower body, but the body temperature will still be low at the end of the operation so the patient is transferred to a tank of water heated to 45° C. As the



B.

A.

Fig. 6.—Chest x-rays taken immediately before surgery (*A*), and 2½ months after surgery (*B*), in Case 1. The heart has shrunk more here than would be expected following surgery in most cases of aortic stenosis.

body temperature rises, the mixture given by the respirator is changed from carbon dioxide and oxygen to oxygen alone, and finally the respirator is disconnected. Rewarming is stopped when the body temperature reaches 33° to 35° C. Usually the patient has spent thirty to sixty minutes in the tank.

CASE REPORTS

CASE 1.—This 12-year-old girl (U. H. No. 890924) was known to have a heart murmur since the age of 2½, but it was not until eight months prior to surgery that she had serious difficulty. At that time she suffered several fainting episodes and chest x-rays showed that her heart had become larger. Despite medical treatment, her condition deteriorated until she was bedridden with chronic congestive heart failure.

On examination she had a systolic murmur at the base with systolic and diastolic murmurs at the apex of the heart as well. The blood pressure was 90/80 mm. Hg. The heart was large (Fig. 6, *A*) and the liver was palpable and tender 8 cm. below the costal margin. There was minimal ankle edema.

Despite her grave condition, surgery was recommended and carried out on Dec. 2, 1955. Her temperature fell to a low point of 26.5° C. and the operation just described was completed without complications. The cusps of the aortic valve were fused to allow only a tiny opening but separation was easy with a knife because the valve was not calcified. Circulation was interrupted for five and three-quarters minutes. After closing the aorta, the mitral valve was explored from the right, but although there was a small regurgitant jet, we felt that this was a relative insufficiency due to the large size of the heart rather than one due to intrinsic disease of the mitral valve.

Her convalescence was marred by a period of hallucinations on the fifth postoperative day which lasted two or three days. Choreiform motions also appeared at this time and they persisted, gradually diminishing, for two to three weeks. Otherwise she has shown striking improvement as is suggested by the pre- and postoperative chest x-rays (Fig. 6). Her blood pressure is 96/60 mm. Hg. She is active and is gaining weight and strength.

CASE 2.—A. N. (U. H. No. 982278) was a 53-year-old man who had suffered several fainting spells, brought on by physical exertion during the year prior to his operation. He fell, breaking some teeth, during an attack and was hospitalized with the tentative diagnosis of acute coronary occlusion. On examination he had a harsh murmur and a thrill over the aortic area. Blood pressure was 108/86 mm. Hg. On x-ray examination the heart was of normal size but calcification could be seen in the region of the aortic valve.

The operation was performed without difficulty, according to the technique just described, on Jan. 31, 1956. The aortic valve was stenosed and rather heavily calcified along the site where the cusps had fused. These cusps were separated with a knife and scissors but, at one commissure, the separation was not carried entirely out to the aortic wall because we feared that too much regurgitation would be produced. After finishing, the index finger could be passed back into the ventricle with ease but the valve cusps remained stiff. The lowest body temperature during surgery was 29.5° C. and the circulation was occluded for four minutes.

His immediate postoperative recovery was uneventful. He is gradually gaining strength and he has had no fainting spells since surgery but there has not been the striking improvement that characterized the first case. Blood pressure is 120/80 mm. Hg.

CASE 3.—This patient (Hosp. No. A-130082) was a 58-year-old man who had suffered from attacks of angina for three or four years. These attacks were becoming more frequent and more severe and he was also troubled with intermittent claudication. On examination there was a thrill and a harsh systolic murmur over the aortic area which was transmitted to the neck bilaterally. There was a diastolic murmur over the apex. Blood pressure was 110/90 mm. Hg. The x-rays showed some prominence of the left ventricle and calcification in the aortic area.

Operation was performed on April 17, 1956. Cooling proceeded satisfactorily and the thoracotomy was started when the body temperature reached 32° C. (temperature reached a low point of 29.5° C. later). The technique described above was followed and a heavily calcified valve was exposed. The three valve cusps were separated but the valve remained stiff. The occlusion period was four minutes and we encountered no serious trouble until after the aortic incision had been closed with the Beck clamp. Shortly after this, a hemorrhage started from a small tear just behind the clamp. This was controlled by re-occluding the cardiac inflow for thirty seconds while the Beck clamp was re-applied. At this point, we found that we had failed to release the distal aortic clamp and, because of this oversight, pressure in the ascending aorta had risen high enough to tear the vessel. Though these difficulties were corrected in a few minutes the heart action became weak and despite two hours of massage, and many other resuscitative measures, including rewarming, the patient died.

At autopsy the valve cusps appeared well separated (Fig. 7). Because of the valvular calcification there may have been some insufficiency but the main cause of death seemed to have been a technical error.

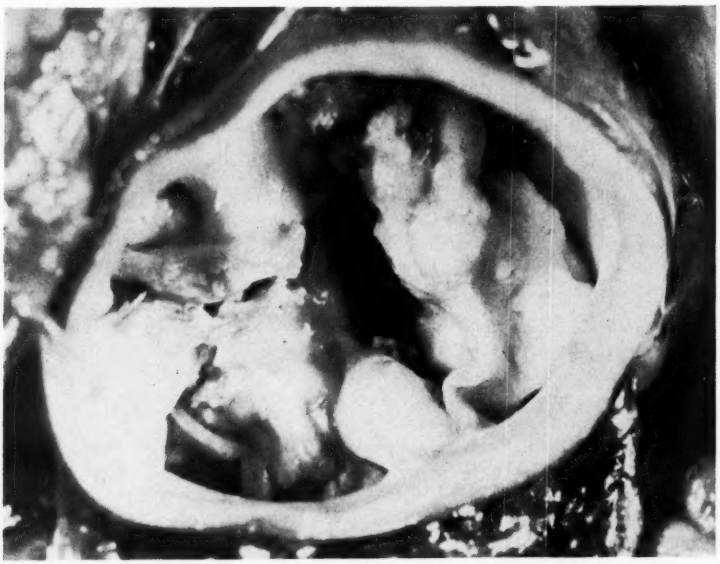


Fig. 7.—The cusp separation obtained in this valve (Case 3) was accomplished at surgery. All three cusps have been freed but they are heavily calcified and stiff.

DISCUSSION

From this work we can conclude that it is quite possible to operate upon the aortic valve under direct vision. It should, in fact, from a purely technical point of view, prove to be as easy to operate on the aortic valve as it is to repair an atrial septal defect; though the risk will doubtless remain higher because the patients are usually older, and because the cardiac function is not restored completely to normal by the operation.

The open operation will doubtless prove to be better than a blind transventricular operation[1] if it can be done with a similar or lower mortality rate. A transventricular dilatation usually does not separate all three cusps satis-

factorily. It is possible, we must admit, that accurate cusp separation could be accomplished through the blind transaortic approach of Swann[19] and Bailey[2] and their associates, for the operator actually has a chance to touch the valve. We have had no experience with this operation but we are inclined to think that it will be less accurate than an open operation, and that it will offer no special advantages unless the operative risk is lower. In contradistinction to the case in aortic valve disease, it should be pointed out that for mitral valve disease a closed operation does provide a special advantage. With a palpating finger in the functioning heart, the degree of regurgitation produced or still uncorrected can be gauged. For such a finger evaluation of aortic valve function, the transaortic, palpating finger is in the wrong position. It should be in the left ventricle.

We believe that the open operation will turn out to be a better way of treating aortic stenosis than closed operations but it will take more experience and a critical evaluation of results to prove this. Doubtless pre- and postoperative measurements of the differential pressure across the aortic valve will have to be part of this evaluation.

Certainly other methods for doing open heart surgery such as cross circulation or pump-oxygenators could be employed to operate upon the aortic valve. Experimentally, Clowes and Neville[4] demonstrated that a pump-oxygenator would work and Lillehei[13] has used a pump-oxygenator successfully in a clinical case. We chose hypothermia because we have had some experience in using it for adults afflicted with other intracardiac defects. Mechanically, it is the simplest method of doing open heart surgery even though it is rather complicated physiologically. Because of its mechanical simplicity it requires only a small operating team. It provides a slowly beating, bloodless heart for the repair and enough time for this operation. Hypothermia may, in fact, provide enough time to repair all currently repairable intracardiac defects. Though for some defects the additional support furnished by coronary perfusion[14] or a small pump-oxygenator[16] may be welcome.

If the direct approach works for aortic stenosis, might it not work for aortic insufficiency as well? No, not without considerable modification. We have no enthusiasm for using the operation just described to expose an insufficient valve in order to try and stitch some of the cusps together or remove some of the calcium. Removal of the calcium is almost certain to destroy the valve and stitches in the valve are unreliable. Experimentally, they pull out postoperatively tearing the valve cusp as they do. A circumferential suture, as an alternative method, seems like a futile gesture in face of a heavily calcified, insufficient valve. Doubtless some sort of a new valve, better than Hufnagel's valve,[7] will be required for insufficiency and also in order to achieve a truly satisfactory operation for stenosis with calcification. Perhaps a flexible valve that will be invaded and become part of the host can be designed. For stenosis without calcification, on the other hand, the open operation with accurate separation of the three fused cusps is ideal, and at least for the present, it may be the best that we can offer for all types of aortic stenosis.

SUMMARY

1. This article describes the technique of an operation for relieving aortic stenosis under direct vision during hypothermia as well as the experimental work that preceeded use of this operation on man.

2. The experimental work showed that open operations could be done on the aortic valve with a low mortality rate and that it was possible to avoid air embolism by thoroughly washing out the left heart before closing the aorta.

3. The accurate separation of all three cusps achieved under direct vision should make this a better operation than blind transventricular or transaortic operations. Nevertheless, for the heavily calcified valve a completely satisfactory result will probably require replacement with a new valve.

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DISCUSSION

DR. HENRY SWAN, II, Denver, Colo.—I should like to say a few words to reinforce Dr. Lewis' comments with regard to the value of the open approach to the aortic valve.

We have had a very limited experience so far with this, being confined to 2 patients. One of these had acquired disease and the other was a child with congenital valvular stenosis. We were quite worried, of course, about the problem of air embolism. It boils down to two aspects. If the aorta is open and the coronary ostia are exposed to the air, will air move in to the coronary arteries? It interested me that it took a long time in the history of medicine to make the crucial experiment, namely, open the aorta and see if it would move in. I think Dr. Clowes was the first to do this, and the answer is that it does not. One can sit and watch the air-blood interface at the mouth of the coronary artery and there is no tendency for air to enter the coronary arteries. The position of the patient is such that the left pulmonary ostium is directly down while the right coronary is directly up. I think this is desirable because if air should enter a coronary artery it will enter the right, in all probability, because of this position and this can be seen immediately and appropriate measures taken should it occur.

The other problem is how to avoid trapping air in the left heart and in the aorta. Dr. Lewis has explained how he has avoided this. We have one slide I would like to show. We have not used Ringer's or saline solution, but we do put a multitude of clamps on, and the one to which I would particularly direct your attention is a large tourniquet around the lung roots. We also put a clamp across the innominate and carotid in case a little bubble of air got caught; this clamp comes off last to avoid any possibility of cerebral air embolus. There is also a clamp across the aorta. The area above the valve is opened and one can look down and get a view of the valve. The value of lung tourniquets is that one can trap enough blood in the lung to fill up the left side of the heart. Thus, the first escape maneuver is to release the tourniquet on one of the lung roots allowing the venous flow to come to the left auricle, fill the left ventricle and then start to move out of the incision. At this point, when the aorta appears completely full, the compression clamp is applied to the incision and the aortic clamp, as Dr. Lewis said, is very rapidly removed.

I think the great value of this procedure will prove to be in treatment of the congenital valve. The one valve we have had a chance to see at operation was quite similar to that which one sees in the pulmonary valve. By very careful placing of the incisions in the exact line of the commissures it was possible to completely relieve the stenosis and at the same time not create any regurgitation. I also understand that Dr. Glen Morrow has had the opportunity to treat one patient in this fashion with subaortic stenosis and was quite pleased with the procedure. I agree, then, wholeheartedly with Dr. Lewis that although the ideal operation for the calcific valve remains to be elaborated, this approach is very practical.

DR. DWIGHT E. HARKEN, Boston, Mass.—Dr. Lewis' paper is up to his own high standards and those of the fine group from whence he comes.

It is better to see, than to feel, and better to feel than not to feel. However, this platitude of "seeing being better than feeling," must be interpreted in the light of the cost, the risk, and the quality of what we do while we see.

We are not arguing over the congenital noncalcific valve. These probably can best be handled by open techniques. However, this may not be necessary in the adult's acquired, noncalcific, aortic stenosis. The lightly fused tricuspid aortic valve may best be managed by finger fracture.

I would like to elaborate on the difference between seeing and feeling, however, in two extenuating dimensions.

The first is the factor of *time*. These comments are based on more than seventy aortic operations. We are mainly concerned with calcific valves in the adult group. We must think in terms of the time we have to work. It may be important to work deliberately 20 or 30 minutes, and thus perhaps accomplish more than we could accomplish during a hasty open procedure under hypothermia. With a pump-oxygenator, the situation may well be different. The second dimension is the *pathologic process*. We return to the fact that in the noncalcific acquired stenosis in adults, open surgery is generally

not necessary. The tricuspid form of aortic stenosis is quite easily managed and manipulated with the finger. The spectrum ranges from the simple to the virtually impossible by any technique. "Impossible calcific barrier" is admittedly a *relative* term, depending on the surgeon and his experience.

When we palpate the valve and fracture it cautiously and, deliberatively using all the time we need, we use an Ivalon sponge operating tunnel at the aortic base. This differs significantly from the tunnel suggested by Dr. William Kirk Swann who uses a cloth tunnel.

The commissure must be opened and mobilized. These leaflets must constitute a valve that is as competent as we can make it and that represents minimal gradient to the transfer of blood.

There are those valves that we cannot correct satisfactorily with our fingers or a valvulotome by open or closed techniques. For this reason, we must address ourselves to the matter of *replacing valves.* Open techniques will be important in such replacement. Until this time, there is a useful place for operating tunnels.

I hope that by the time we meet again, we will have a competent permanent, nongradient valve, that does not propagate emboli.

DR. GERONIMO N. GUASTAVINO, Buenos Aires, Argentina.—I have enjoyed this interesting paper very much. With the object of overcoming some of the problems of aortic stenosis surgery, an instrument has been devised to be used in the aortic approach.

(slide) This is a long plastic prism, with one surface wider than the others, which carries a sliding mechanism with two acting sharp members which can be protruded closed, under visual control, through the stenotic opening.

(slide) The triangular shape of the instrument may be seen. The instrument is introduced through the aortic approach; both blades are opened after introduction through the stenotic opening. Each blade may be open or shut separately permitting individual section of any commissure; if necessary one blade may section for a greater length than the other. When the sliding mechanism is drawn back the blade cuts from below upward.

(slide) This shows the blades introduced through the stenotic opening of a pulmonary valve. The illustration was prepared on a specimen of valvular pulmonic stenosis. Next you see the nature and extent of the section of the stenotic valve produced when the sliding mechanism of the instrument was withdrawn; notice particularly how the valve is cut as the blade comes from below.

Anatomic results are similar in the case of aortic stenosis. As you know, congenital aortic stenosis resembles anatomically pulmonary valve stenosis.

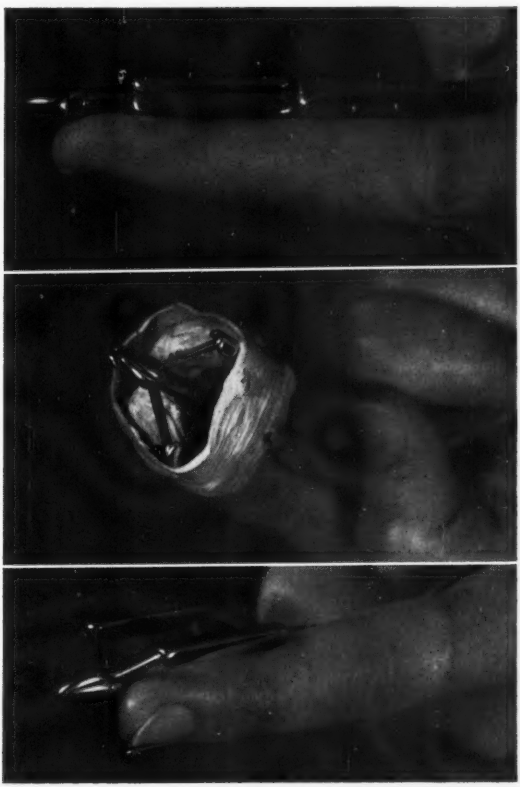
(slide) When necessary, as in calcific aortic stenosis, both blades may be replaced by another sliding mechanism which carries a guillotine knife for use in very firm valves.

We believe that this instrument may permit (1) visual control of the aortic valve and stenotic opening from above; (2) introduction under visual control of two sharp acting members into the stenotic opening; (3) section of the commissures from below upward, the result of which can be visually controlled and, if necessary, the acting members may be reintroduced to make as many sections as are necessary; and (4) the triangular shape of the instrument produces minimal obstruction of the aortic lumen and permits introduction of a catheter for transfusion if necessary.

DR. HENRY B. LARZELERE, Toledo, Ohio.—Ever since the initial efforts of Horace Smithy, we have looked for the successful means whereby aortic stenosis may be treated. Digital and instrumental efforts via the left ventricle have produced results which most surgeons have decried and abandoned as too dangerous and too inconclusive. Into the "arena," labeled experimental surgery, have been placed more recent efforts via the aorta itself, namely, the transaortic retrograde procedures. All agree that the latter approach produces less heart strain; in other words, rarely cardiac arrest or fibrillation. Yet the dangers of hemorrhage and embolization still seem to make the risk out of all proportion

to the expectations. Within the past year, attack under direct vision has met with some success. Reports today are very interesting and provide again great expectations. We are all enthusiastic about these promises and evident results, as shown today by Dr. Lewis.

However, there remains the need for much more refinement and re-evaluation on the part of thoracic surgeons before the surgery of this valve is shelved or relegated entirely to direct vision efforts. Indeed, the patient with aortic stenosis cannot wait out his turn for certain highly specialized teams to treat his valve. He must be treated or die. As we all know, when the symptoms of aortic stenosis border on, or become, those of congestive heart failure, the patient generally is faced with only six to eighteen months of life expectancy. Therefore, an instrument and a technique for the proper treatment must be perfected to allow all patients with this disease a chance for extended life.



Such means are available, but these means must be perfected. Most previous instruments are quite inadequate and too cumbersome. We wish to present for the first medical showing the vastly improved Donaldson instrument, and to re-define the problem of aortic stenosis surgery. We wish to re-establish the true worth of the aortic retrograde technique.

Hemostasis and actual valve commissurotomy are the two features to be emphasized. For adequate hemostasis several devices are good. We have come to use the plastic tunnel devised by Swan although, when available, we prefer the pericardial homograft pouch method of Bailey. To effect the best hemostasis in the use of either tunnels or pouches,

it is necessary to use a strong purse-string suture placed at the distal end of the tunnel, several millimeters from the edge so as to offer a cuff or surface always encircled by the suture material. No knot should be placed in this purse string. An important further factor of hemostasis is the use of an encircling umbilical tape placed midway along the tunnel, so that entrance and withdrawal of finger and/or instrument can be performed in a stepwise fashion, offering at all times a double control. Maintenance of this encircling tape in a fixed position is made easy with a small fixation suture, attaching the tape to the tunnel wall.

Experience has shown that approximately half of the stenotic aortic valves can be adequately opened by digital technique alone. However, in the remaining cases, careful and constantly guided instrumentation is essential. For the calcific valve, loaded with granular or pedunculated calcium deposits, it seems brutal to assume that blunt digital efforts, with the inherent risk of embolization, are to be accepted. In such cases a shearing positive force, applied simultaneously to all the diseased commissures, is necessary. In this way embolization is kept to a minimum.

The Donaldson instrument very capably achieves this goal; and as a dilator has been used many times successfully at several centers. However, too often, momentary short cuts in its use have caused fatalities. Each "pass" or engagement of the instrument into the valve orifice must be guided. Completely blind maneuver without finger-tip control leads to embolization, torn valve cusps, blocked or damaged coronary orifices, and disruption of hemostatic control. Dr. Samson has been kind enough to aid me in presenting a silhouette of this thin-shafted, rugged, all stainless steel instrument. Guided instrumental engagement is made easy by placing the instrument along the palmar aspect of the finger. The finger tip is made to "seat" carefully into the sinus of Valsalva; the instrument is then engaged, and the commissurotomy is effected. The instrument may well have its greatest place in the open surgery on the aortic valve, as well as in the so-called closed maneuver.*

DR. CHARLES P. BAILEY, Philadelphia, Pa.—Of course you understand that we are very fond of Dr. Lewis and he of us. Otherwise, he probably would not have picked on Philadelphia so much. Speaking of priorities, he raised the question: I performed the first historic open heart operation for an atrial septal defect under hypothermia four days before he did (Aug. 29, 1952). The difference was that my patient died while his lived. Maybe that experience gave me a more dismal view of hypothermia than he and Dr. Swan have come to accept. John Gibbon of Philadelphia was the first in this country, and perhaps in the world, successfully to open a heart with the use of a heart-lung machine.

During the past six years, we have operated upon a total of about 450 patients with aortic stenosis. A few of the early procedures now seem pretty antiquated. We performed over 200 transventricular dilatations of the aortic valve and operated on another 200 by the supravalvular route. We now insist on a tricommissural opening in every normally formed valve or else we consider the operation a failure; the mortality in the transaortic procedure is about 15 per cent. Recently, hearing that Dr. Lillehei had opened one of these valves under direct vision with a pump and oxygenator, we have decided to do likewise in certain cases and now have operated upon 2 patients using the Friedland-Gemeinhardt bubble-type oxygenator. We used the Blanco, Adam, and Fernandez method of cannulating the coronary sinus for retrograde perfusion of the myocardial capillary bed which Dr. Lillehei has used also. One patient was a 14-year-old boy with congenital aortic stenosis and subaortic stenosis. The other was a 24-year-old man with what proved to be an acquired and calcific type of aortic valvular stenosis. The method worked very nicely. In both cases, we were able to obtain the same good tricommissural opening that we have come to expect with the closed method. In both we abolished the gradient as we should have

*It is contrary to the policy of this JOURNAL to publish illustrations with the discussion. However, an exception has been made in this case, both because it is easier for the reader to get a clear idea of the instrument by seeing photographs of it, and because of the Editor's desire to give all possible assistance to the development of this very important new field of operative surgery.—EDITOR.

expected with the closed method. No regurgitation was produced. We took 16 and 24 minutes, respectively, for the definitive surgery. I must point out, however, that while the open approach would seem to be very useful in congenital aortic valvular disease in which the commissures might not be normally formed and also in calcific aortic stenosis since there is danger that a fragment might be dislodged, each of these procedures took us more than 7 hours and we had to sit up with the patients afterward to be sure they did not bleed to death or something like that. We are inclined to think that the usual 3-hour operation by the closed technique might have many practical advantages in some of these patients. However, this is a wonderful presentation of a fine new approach in certain of these cases. Unquestionably, open surgery for aortic stenosis is here to stay.

DR. C. W. LILLEHEI, Minneapolis, Minn.—I would like to supplement Dr. Lewis' fine presentation by describing yet another method for extending the benefits of direct vision reparative surgery to the aortic valve and other left heart lesions.

The ready availability of a simple, straightforward, and effective pump-oxygenator for human use has shifted the emphasis upon research in our experimental laboratory from that of the development of methods for open cardiotomy which occupied our attention for so long, to that of application of the advantages of open cardiotomy to the treatment of various cardiac lesions likely to benefit by this approach. As a result, about a year ago the problem of working upon the left heart commenced in the experimental laboratory. In working in this area in an unhurried manner there are at least two obstacles that need to be overcome. One is the prevention of coronary air embolism; the other is the maintenance of some coronary blood flow to the myocardium to prevent muscle hypoxia.

It may be suggested that direct vision reparative procedures upon the aortic valve be carried out rapidly enough to allow their completion during a brief interval without coronary blood flow. While this is certainly possible, we have rejected this approach for two reasons. First, a time limitation is imposed which is undesirable for the patient. Second, however short the procedure can be made, the myocardium at the end of such an interval is left in a hypoxic state. This is also true when selective cardiac arrest without coronary circulation is induced. In critically ill patients, this metabolic oxygen debt within the cardiac muscle could be intolerable and vitiate an otherwise successful surgical procedure. The same considerations in some measure pertain to the use of hypothermia and temporary arrest of the circulation for exposure of the aortic valve.

The method that we have used to avoid these obstacles has been to totally by-pass the heart and lungs in the usual fashion with the pump-oxygenator and to retroperfuse the coronary venous system with oxygenated blood through a separate catheter inserted into the orifice of the coronary sinus. Pratt, in 1898, first pointed out that the myocardium could be nourished in this fashion. Drs. Blanco, Adam, and Raffucci from the department of surgery at the School of Tropical Medicine in San Juan, Puerto Rico, have reported on experiments applying these observations. Likewise, Beck has made use of this principle in his revascularization procedures. However, I might emphasize one important difference in utilization of this principle for open heart surgery, that is, with the ascending aorta open (and the pressure within, zero) the resistance to retrograde flow through the coronary system is slight and adequate flow occurs with a very low pressure. In the clinical cases, we have pumped only enough blood into the coronary sinus to maintain a healthy pink color in the myocardium and this amounts to a mere trickle since the oxygen requirements of the nonworking heart are low.

In our experimental laboratory, Dr. Gott has consistently maintained the hearts of dogs on retrograde coronary sinus perfusion with the aorta open for 30 minutes with only an occasional instance of arrhythmia. I might mention that the nonworking canine heart usually fibrillates or arrests in far less time when the coronary circulation is cut off completely.

Clinically we have utilized total by-pass of the heart and lungs with retroperfusion of the coronary sinus in patients with five different types of pathology involving the left side of

the heart. In each case, the human heart remained a healthy pink color and continued to beat at a slow regular rate throughout the interval of maintenance by retroperfusion.

The first patient, a 38-year-old woman with calcific aortic stenosis, was operated on in January, 1956.

(Slide) This is her preoperative chest x-ray showing the large amount of calcium in the aortic valve. Physically, she was in Class IV, being completely incapacitated. This type of case has given rather discouraging results when managed by closed methods. This lady's aortic valve was exposed to direct vision for 11¼ minutes while the cusps were mobilized accurately at their commissural junctions, and some of the verrucous calcium deposits trimmed off the leaflets. There were no arrhythmias and her postoperative improvement has been dramatic, and sustained to date.

(Slide) In a 7-month-old infant with an aortic pulmonary septal defect, this technique allowed us to simply divide the fistulous communication between the empty ascending aorta and main pulmonary artery, and oversew the open ends. In this case, the heart was supported by retrograde coronary sinus perfusion for 7 minutes without arrhythmias. The infant died ten days later of a diffuse bronchiolitis probably aggravated by the severe pulmonary hypertension present preoperatively. However, this approach converted what is often an impossible dissection by closed methods into a simple open procedure.

(Slide) The third patient, 10 years of age, had a ruptured sinus of Valsalva into the right ventricle. Her blood pressure prior to corrective surgery was consistently 110/0 mm. Hg. After the heart and ascending aorta were rendered bloodless by this technique, the defect was closed with interrupted silk stitches placed under direct vision. Immediately following corrective surgery, she had a diastolic pressure of 70 mm. Hg and convalescence was uncomplicated.

Two other types of lesions have been managed in this fashion. Multivalvular (aortic regurgitation, mitral stenosis) rheumatic heart disease in a 52-year-old patient treated successfully by direct vision aortotomy and left atrial cardiotomy; and in a 15-month-old baby with complete transposition of the great vessels, both coronary arteries were moved with the aorta to the left (posterior) ventricle, the pulmonary artery was joined to the right (anterior) ventricle, and multiple ventricular defects were closed. This latter patient died in the postoperative interval but the heart was maintained without arrhythmia and with an excellent beat and color for 16 minutes while the coronary arteries and aortic valve were anastomosed to the posterior ventricle.

In conclusion, this experience has suggested that this method is a valuable adjunct to the pump-oxygenator for left heart surgery. Further, if one lets his imagination wander for a moment several other applications are apparent, such as replacing the ascending aorta for aneurysms or to permit the cross-clamping of the main coronary arteries for a temporary period to allow direct surgical procedures upon these vessels.

DR. WILLIAM H. MULLER, JR., Charlottesville, Va.—I, too, would like to congratulate Dr. Lewis on this excellent accomplishment, but I would also like to raise the question of the advantages offered by the open procedure over those offered by the closed procedures that are now utilized for acquired aortic stenosis. I would agree with those who say that the open technique for congenital aortic stenosis is better because one has a more normal valve to open. The aortic valve in acquired aortic stenosis is often so deformed and calcified that residual commissural fusion lines are not discernible. Actually, the goal in opening the aortic valve is to relieve the gradient across it and this can be done in almost all instances with either the transventricular or the retrograde approach. I think we will probably continue to use these outmoded procedures until the valve can be replaced with a satisfactory prosthesis.

DR. J. H. KAY, Bethesda, Md.—Drs. Kaiser, Gaertner, and I have used a similar method experimentally as well as clinically. Eleven dogs were cooled to a final rectal temperature of 32° C. and a right anterior thoracotomy was performed through the fourth intercostal space. The base of the aorta was exposed on the right side at the origin of the

aortic valves by retracting the right auricular appendage caudad. After performing inflow occlusion the aorta was cross-clamped at the origin of the great vessels. The base of the aorta was then opened for 4 minutes. This gave excellent exposure of the aortic valves. The caval ties were released and all the air flushed from the left ventricle and aorta. The incision in the aorta was clamped and the clamp used for cross-clamping the aorta was removed. There was no evidence of cerebral, coronary, or peripheral emboli. All 11 dogs were chronic survivors. We then operated on the following 2 patients with Dr. Morrow. Using a bilateral anterior incision as described by Dr. Lewis, the open approach was used to cut the stenotic aortic valve in a very ill, middle-aged woman. Because of mitral stenosis, a mitral commissurotomy was also done. Although this patient was alert and awake postoperatively, she died five days later of a pulmonary embolus. The second patient had a subvalvular aortic stenosis that was satisfactorily treated with the open approach. A median sternotomy was used in this patient. It gave excellent exposure. We feel that the postoperative period will be much easier for patients with a median sternotomy than with the bilateral anterior incision. We agree wholeheartedly with Dr. Lewis that aortic valvotomy under direct vision is the best present-day method of treating aortic stenosis.

DR. LEWIS (Closing).—I would like to thank the discussants for their stimulating comments. It is gratifying to find so much interest in this type of surgery, and I am especially delighted to find some supporters among the group. I am sure there are more among you who could have stood up to support this, for I know of a few others who have actually used the technique.

If Dr. Bailey were not such a gracious gentleman I am sure his response to my comments would not have been so kind. I am humbled by his attitude as well as by the large number of cases he has operated on. But he still leaves me rather confused as to how my priority rating stands. So I think I will have to go home and put that scissors aside, in case the Smithsonian Institution does finally ask me for it.

So far as Dr. Lillehei's comment concerning trimming of the calcium off these valves is concerned, I would warn any of you who might want to try this, to try it in dead specimens first. In our own experience this seems to be an impossible technique. Usually the calcium extends to both valve surfaces and if you take out the calcium you make a hole in the valve, so we do not try to trim calcium out of these calcified valves.

I am sure there will always be some, like Dr. Muller, who will stick to the older techniques as long as they can. Any active society always has a few members who are slow to accept change. Others of you I am sure will soon come to using an open technique on these cases.

INDICATIONS FOR LOBECTOMY IN THE TREATMENT OF CARCINOMA OF THE LUNG

JOSEPH L. ROBINSON, M.D., JOHN C. JONES, M.D., AND B. W. MEYER, M.D.
LOS ANGELES, CALIF.

IN presenting this subject for discussion by the members of the Association, we should like to have it clearly understood that we are not raising the question of whether lobectomy is a better operation than pneumonectomy in the treatment of pulmonary carcinoma, but rather, in treating a human being for carcinoma of the lung, under what circumstances is it preferable to remove less than the entire lung? We believe that every surgeon worthy of the name must, in treating a given patient, temper the zeal of the surgical technician with the judgment of the physician within him. His aim in treating a patient must be not only to bend every effort to save the patient's life, but to do so in such a manner as to make that life as happy and satisfactory in the living as is possible. Because of the multiplicity of clinical factors which bear upon each individual patient, "indications" for surgical procedures must serve not as absolute criteria but rather as guideposts to aid the surgeon in reaching a decision.

The question of the use of lobectomy in treating carcinoma of the lung has been discussed before this Association several times,[1, 2, 4, 9, 10] but a reading of the accounts of the discussions of these papers leaves one with the uneasy impression that what was said by the discussants may not accurately reflect common practice. Perhaps a quotation from Churchill's[5] closing remarks in 1950 will illustrate our meaning: "I have been called a scoundrel and a rascal for twenty years for saying that under certain circumstances I elected to perform a lobectomy for cancer. Many visitors, both from this country and abroad, have discussed the matter with me, and their comments very often have been, 'I am glad to see that you do a lobectomy occasionally, because I do, too, but I don't dare say so.' "

This situation has not been helpful in the teaching of thoracic surgery to graduates or undergraduates, and one of us (J. C. J.) has observed considerable confusion in the minds of candidates appearing for examination for certification by the American Board of Thoracic Surgery. Therefore, we decided to try to find out by the use of a questionnaire just what use the members of the Association are making of lobectomy in treating pulmonary carcinoma in their daily practice. We should like to present to you first a brief summary of our own practice in regard to lobectomy, together with the results thus far of that practice; and second, a tabulation and discussion of the answers to our questionnaire.

Read at the Thirty-sixth Annual Meeting of The American Association for Thoracic Surgery at Miami Beach, Fla., May 7 to 9, 1956.

Until 1950, the question of lobectomy for carcinoma of the lung had not assumed serious proportions for us, and of 79 resections for carcinoma, only 3 had been lobectomies. But in late 1950 and early 1951, an attempt was made in Los Angeles County to survey by minifilm chest x-ray the entire adult population. One of the results of that survey was to bring eventually to the operating table a number of patients with small, round, circumscribed, peripheral, asymptomatic lesions whose etiology could not be determined until the tissues were placed in the hands of a pathologist. In those instances in which the pathologist reported a malignancy, our policy has been as follows: (1) if the lesion is well removed from the fissure or the adjacent lobes, and from the point of transection of the bronchus, and the mediastinal and hilar nodes do not appear to be involved, and the pathologist reports no involvement of the peribronchial lymph nodes, we are satisfied to do only a lobectomy; (2) if the above conditions are not satisfied, we proceed to do a total pneumonectomy *unless* the patient's cardiorespiratory situation contraindicates it, in which case we do not resect any more lung tissue, but do dissect out all the available lymph nodes.

The results of that policy upon our resections are shown in Table I. The proportion of lobectomies, which prior to 1950 was 3.8 per cent, jumped to 30.4 per cent in 1950, and for the past 2 years has exceeded the pneumonectomies.

TABLE I. OPERATIONS FOR PRIMARY CARCINOMA OF THE LUNG

YEAR	NUMBER OF OPERATIONS	NUMBER OF RESECTIONS	NUMBER OF PNEUMONECTOMIES	NUMBER OF LOBECTOMIES	PER CENT LOBECTOMIES
Prior to 1950	160	79	76	3	3.8
1950	36	23	16	7	30.4
1951	38	18	13	5	27.8
1952	41	24	18	6	25.0
1953	37	17	9	8	47.0
1954	38	26	11	15	57.7
1955	26	13	5	8	61.5
Total since 1950	216	121	72	49	40.5
Total	376	200	148	52	26.0

A one-year follow-up of the patients operated upon during that period (January 1, 1950 to January 1, 1955) shows (Table II) that there were 41 lobectomies, after which 21 patients, or 51 per cent, have lived one year or more, and 67 pneumonectomies, after which only 4, or 6 per cent, have lived one year or more.

TABLE II. RESECTIONS FROM JANUARY 1, 1950 TO JANUARY 1, 1955

	NUMBER RESECTED	NUMBER ALIVE ONE YEAR OR LONGER
Lobectomies	41	21—51 %
Pneumonectomies	67	4— 6 %
Total	108	25—23.2%

We do not have a sufficient number of patients to make a five-year follow-up meaningful, but reference to the mortality curve published in a previous paper, and which is shown in Fig. 1, indicates that a three-year follow-up is quite satisfactory for purposes of comparison.[7]

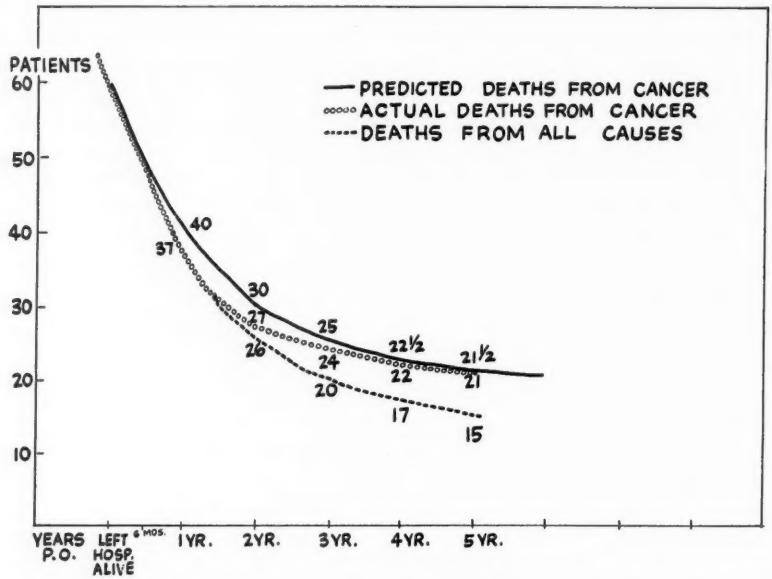


Fig. 1.—Primary bronchogenic carcinoma of the lung. Follow-up study of 64 patients five to eleven years after pulmonary resection.

Table III shows such a comparative follow-up of the lobectomies and pneumonectomies. Of 21 patients upon whom lobectomy was performed at least three years ago, 15, or 71.4 per cent, were alive at the end of the three-year period. Of 123 patients having a pneumonectomy, 20, or 16.3 per cent, were alive at the end of three years. The reason why the three-year follow-up on lobectomies appears better than the one-year follow-up is that most of the patients in the early period were patients with a peripheral, coin, or survey type lesion with a relatively good prognostic outlook, whereas later many patients were included with poor cardiorespiratory function in whom lobectomy was a compromise operation.

TABLE III. RESECTIONS FROM JANUARY 1, 1942 TO JANUARY 1, 1953

	NUMBER RESECTED	NUMBER ALIVE 3 YEARS POSTOPERATIVE
Lobectomy	21	15—71.4%
Pneumonectomy	123	20—16.3%
Total	144	35—24.3%

Of course a comparison of follow-up statistics on pneumonectomy and lobectomy patients is in itself rather meaningless, since many more patients

with a good prognosis will be included in the lobectomy than in the pneumonectomy group, and the survival rate is bound to be better by virtue of this selection. It has been argued[6] that survival rates would be better in even the group of patients with small peripheral lesions if they were treated by pneumonectomy rather than lobectomy. The only way to conclusively answer this question would be to conduct the impossible experiment of pairing a large number of patients with similar lesions, and doing lobectomy on one and pneumonectomy on the other, and since this experiment cannot be performed we must draw conclusions from other methods of study. One such method is to collect the considered opinions of surgeons who are treating patients with carcinoma of the lung, and this we have attempted to do by means of a questionnaire, which is reproduced in Table IV.

TABLE IV. THE QUESTIONNAIRE

1. Do you perform lobectomy for carcinoma of the lung	
a. For a primary carcinoma?	Yes____ No____
b. For metastatic carcinoma?	Yes____ No____
2. If so, do you use lobectomy	
a. As an operation of choice under certain conditions?	Yes____ No____
b. Only in cases in which there is some contraindication to pneumonectomy?	Yes____ No____
3. Given the indications which you consider would make the operation one of choice, is it your experience that it offers the patient as good a chance for long-term survival as does pneumonectomy?	Yes____ No____
Further comments:	

In making up the questionnaire which was sent to the surgeon members of the Association, we attempted to gain certain information regarding present-day practice in the use of lobectomy in the treatment of cancer of the lung. We wished to find out: (1) to what extent lobectomy is being used in treating pulmonary carcinoma; (2) under what circumstances it is being used, for example, as an operation of choice, as a compromise operation in patients with poor cardiorespiratory function, or as a purely palliative procedure; and (3) whether it has had sufficient use to enable thoracic surgeons to form an opinion as to its efficacy as a curative procedure in treating carcinoma of the lung. In addition, we hoped that we might obtain further expression of opinion on the subject, and therefore added an inviting "further comment" column to our questionnaire. We have been very gratified by the response of the members of the Association, not only in the number of answers we have received (318 out of 400 sent out), but even more so by the high proportion of surgeons who made additional comments (208, or 68.4 per cent of the 304 usable returns).

TABLE V. TABULATION OF ANSWERS TO QUESTIONNAIRE

	1-A	1-B	2-A	2-B	3—PER CENT
No	20	17	39	87	54— 17.8
Yes	282	279	236	123	173— 56.9
Qualified yes	0	0	2	2	25— 8.2
Unanswered	2	8	27	92	52— 17.1
Total	304	304	304	304	304—100

ANALYSIS OF REPLIES (Table V)

1. Extent of use of lobectomy in treating pulmonary carcinoma.

A. *Metastatic carcinoma:* Two hundred and seventy-nine, or 91.8 per cent, of those answering the questionnaire resect solitary metastatic pulmonary lesions. The extent of the resection is kept as small as possible, and may be a subsegment, segment, or a lobe.

B. *Primary carcinoma of the lung:* Two hundred and eighty-two, or 92.8 per cent, use lobectomy in treating primary carcinoma of the lung.

2. Under what conditions is it used?

A. *As an operation of choice:* Two hundred and thirty-six, or 77.6 per cent, perform lobectomy as an operation of choice under circumstances of their own choosing. Thirty-nine, or 12.8 per cent, do not use it as an operation of choice, and 9.6 per cent did not answer the question.

B. *As a compromise operation:* One hundred and twenty-three, or 40.5 per cent, said they use it only when there is some contraindication to pneumonectomy. There is some discrepancy here, since 77.6 per cent had said they use it as an operation of choice, but it is apparent from the comments made that the 77.6 per cent was made that large by some who referred to its use in metastatic carcinoma, and the 40.5 per cent who answered yes to B, were referring to its use only in primary carcinoma. It would appear then, that about 60 per cent of those who make use of lobectomy in treating primary carcinoma of the lung, use it as an operation of choice, and 40 per cent use it only as a compromise operation in patients they do not consider suitable for pneumonectomy.

3. Has it had sufficient use to enable thoracic surgeons to form an opinion as to its efficacy? We were somewhat surprised that only 52 surgeons, or 17.1 per cent, were of the belief that they had not had sufficient experience to justify an opinion on this question. The question asked was "Given conditions which you consider make the operation one of choice, is it your experience that it offers the patient as good a chance for long-term survival as does pneumonectomy?" One hundred and seventy-three, or 56.9 per cent, answered yes. An additional 25, or 8.2 per cent, answered yes with reservations, chiefly concerning the small number of cases they had seen. Fifty-four, or 17.8 per cent, answered no. So, of the 227 surgeons who expressed an unqualified opinion, 76 per cent, or better than 3 out of 4, believe that in properly selected patients, a lobectomy offers as good a chance for long-term survival as does a pneumonectomy.

The comments made in the replies to the questionnaire varied considerably, both as to context and as to extent; and they make very interesting reading. To a large degree they had to do with the indications for the selection of patients for lobectomy, the poor over-all experience in attempting to cure pulmonary carcinoma, the use of other means (radiation or chemical) in conjunction with resection, or the reasons why lobectomy is, or is not, a satisfactory method of attacking primary carcinoma of the lung. Of the 208

who made some comment, 81 specifically listed poor cardiorespiratory function, age, or other factors which make the patient a poor risk for pneumonectomy, as an indication for lobectomy. Seventy-eight listed a small, circumscribed, peripheral lesion as an indication for lobectomy, and 31 of these included negative lymph nodes among the criteria. Six even went so far as to say that they consider lobectomy the operation of choice whenever it is anatomically feasible. Twenty-five mentioned palliation as an indication for lobectomy. There were some other specific indications, such as the cell type and the lobular location of the lesion. Twenty-three gave various reasons why pneumonectomy is a superior operation in all cases, and of these only 3 mentioned specifically the Brock-type lympho-pulmonary resection[3] as the ideal procedure.

DISCUSSION

The success or failure of surgical resection in curing carcinoma is determined by whether or not extension has occurred into tissues other than those resected. In the case of carcinoma of the lung, direct extension can usually be determined at the time of surgery. Lymphatic extension may or may not be determined. Blood stream extension or bronchogenic spread is not apparent until symptoms or signs of it appear. Factors, such as the rate of growth of the tumor, cell type, lymphatic blockage, chance, and others, are important in determining whether extension occurs early or late, but once surgery is completed the die is cast. Because time is always involved in direct or lymphatic extension, it has been accepted as good surgical practice to make a wide resection of carcinomatous tissue (including en bloc resection of its lymphatics) in order to remove any microscopic extension of malignant cells into adjacent tissue or lymph channels. Those who advocate complete pneumonectomy with widespread lymph node resection are trying to apply to the lung the same technique as is applied, let us say, to carcinoma of the breast. But the lung differs quite markedly, anatomically, from the breast, particularly as regards lymphatic drainage. The question of direct extension into adjacent tissues or along the involved bronchus can usually be quickly settled by the surgeon or the pathologist at the time of surgery. But because of the widespread intercommunication of the lymph channels from the two lungs, it is questionable whether a widespread removal of the lymphatics from only one side of the mediastinum is worthwhile. Rouviere in his classical description of the lymphatics of the lung[11] had this to say, "Nodes of the tracheal bifurcation form a crossroad where lymphatic vessels which issue from the diaphragm, the heart, the cardia, the esophagus, the inferior part of the trachea, the bronchi and the lungs meet directly or by means of lymphoid relays." Others have confirmed his findings.[8, 12] The normal drainage from the left lower lobe is into the glands of the right upper mediastinum, and we are sure that most of us have seen patients in whom, following resection of a carcinoma of the left lower lobe, the earliest manifestation of recurrence has been in the glands of the right upper mediastinum. This factor of lymphatic intercommunication, together with its increased morbidity and mortality

rates, has apparently prevented any large number of thoracic surgeons from adopting the so-called radical pneumonectomy as a routine procedure. Based upon comments made in replies to our questionnaire, it is apparent that a not insignificant number of surgeons have adopted the practice of doing a local resection of the lesion, whether that requires lobectomy or pneumonectomy, and then depending upon radiation or chemical means to treat any involved lymph nodes.

SUMMARY AND CONCLUSIONS

1. For the past six years in a selected group of patients, we have been making increasing use of lobectomy in our surgical attack upon primary carcinoma of the lung. Our experience to date has led us to be satisfied to continue this policy. Of 123 patients treated by pneumonectomy, the three-year survival has been 16.3 per cent, and of 21 lobectomies, the three-year survival has been 71.4 per cent.

2. A survey has been conducted among the surgeon members of The American Association for Thoracic Surgery to determine to what extent and under what conditions they are using lobectomy in treating patients with carcinoma of the lung. The results of that survey show that of 318 replying, (1) 91.8 per cent use lobectomy in treating metastatic pulmonary carcinoma, (2) 92.8 per cent use lobectomy in treating primary pulmonary carcinoma. About 60 per cent use it as an operation of choice in treating primary carcinoma of the lung. Forty per cent use it only as a compromise measure in patients whom they feel would not tolerate a pneumonectomy. (3) Of the 318 who replied, 227 surgeons believe that they have sufficient experience with lobectomy to be able to offer an unqualified opinion regarding its efficacy. Seventy-six per cent (56.9 per cent of the total replying) believe it offers as good a chance for long-term survival as does pneumonectomy, and only 24 per cent (17.8 per cent of the total) do not.

3. Based upon the replies to the questionnaire distributed to members of the Association for Thoracic Surgery, as well as upon our own experience, we suggest the following as a guide in the selection of patients with primary carcinoma of the lung to be treated by lobectomy.

A. As an operation of choice. A peripheral lesion located well away from the fissures or adjacent lobes, with a satisfactory proximal length of uninvolved bronchus, and with no apparent extension to adjacent tissues, nor to the peribronchial, hilar, or mediastinal lymph nodes.

B. As a compromise operation. In patients whose lesion does not satisfy the above conditions, but whose cardiorespiratory or other clinical condition makes them unsatisfactory subjects for total pneumonectomy.

C. As a palliative operation. In patients who, at the time of operation, are found to have a lesion which obviously cannot be completely eradicated surgically, but in whom a clinical appraisal has indicated that such symptoms as hemoptysis, cough, or infection can be controlled better by lobectomy than by nonsurgical means.

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(For Discussion, see page 517.)

COMMON FACTORS IN LUNG CANCER SURVIVORS

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EACH year more long-term lung cancer survivors are recorded. Significant numbers from a single institution have not been reported, however. A recent review of cases seen in our clinic has made possible a search for common factors in five-year survivors. Information gained from the study has aided the simplification of management procedure.

Records of 101 three-year survivors were surveyed. Fifty-five of these cases lived more than five years after pulmonary resection. None of the five-year survivors presented evidence of cancer recurrence. Thirty-three are alive now more than five years, and 17 are living now more than ten years. The remaining 5 died of other causes, from five to thirteen years after surgery. All were treated in the nineteen-year period from June 1932, to May, 1951.†

Table I. Primary Pulmonary Carcinoma
June, 1932—May, 1951

Proved histologically	733*	
Explored	457	(62%)
Resected	261	(37%)
Operative mortality	56	(12%)

*44 Adenomas excluded.

In this study, age and sex were not important factors as to survival. The patients in this group were slightly younger than the other cases seen during the same period, but age distributions were similar in the two groups (Table II).

Table II. Primary Pulmonary Carcinoma
June, 1932—May, 1951

Age	Five-year survivors (55) (per cent)	All others (678) (per cent)
Under 40	7	5
40-49	23	20
50-59	42	40
60-69	26	30
70 and over	2	5

Read at the Thirty-sixth Annual Meeting of The American Association for Thoracic Surgery at Miami Beach, Fla., May 7 to 9, 1956.

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†During this period, 733 cases of histologically verified lung cancers were observed. (Table I.) Of those 678 who did not survive five years, 402 were explored, 206 had resections, and 54 had radiotherapy. Sixty-seven of the resections were performed with hope of cure; 50 patients had regional lymph node involvement; 89 had gross extension to adjoining viscera. Over-all operative mortality was 12 per cent, including all deaths occurring within thirty days after anesthesia. During the same 1932 to 1951 period, 44 cases of bronchial adenoma were encountered. These are not included in this report. However, in Fig. 1 comparative survival rates of adenoma and cancer are shown.

The youngest five-year survivor was 24 years of age at the time of surgery, and the oldest was 70. In both groups there were seven times as many men as women (Table III).

TABLE III. PRIMARY PULMONARY CARCINOMA
JUNE, 1932—MAY, 1951

SEX	FIVE-YEAR SURVIVORS (55) (PER CENT)	ALL OTHERS (PER CENT)
Male	87	87
Female	13	13

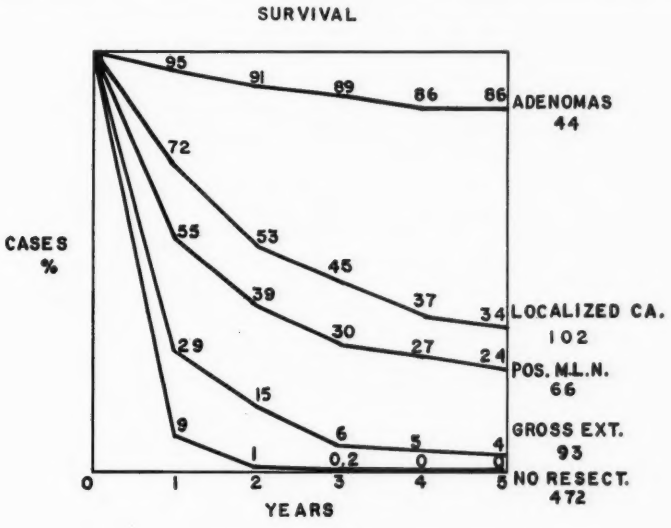

Fig. 1.

Symptoms in those who survived five or more years were not distinctive. Cough, hemoptysis, chest pain, and symptoms of respiratory infection were the most common initial manifestations (Table IV). At the time of resection,

TABLE IV. FIFTY-FIVE FIVE-YEAR SURVIVORS (SYMPTOMS)

INITIAL	SYMPTOMS	AT DIAGNOSIS
26		
7	Cough	40
7	Hemoptysis	23
7	Chest pain	15
7	Respiratory infection	12
6	Systemic	14
3	Dyspnea	5
	Wheeze	

all but 5 of the 55 patients had pulmonary symptoms. In addition, 13 had systemic symptoms of weight loss, anorexia, malaise, or fatigue. One patient had fatigue as his sole complaint. Seven of the survivors had only x-ray evidence (survey). Some of these developed significant symptoms by the time

they were presented for surgery. Only 18 of the 55 patients had objective signs in the chest. Findings included diminished breath sounds, wheeze, bronchial breathing, and dullness to percussion.

Preoperative histologic verification of the diagnosis was possible in only 24 cases. Bronchoscopic biopsy was obtained in thirteen of 48 procedures (27 per cent; Table V). Cytology revealed malignant cells in 15 of 27 cases (56 per cent; Table VI). Positive findings in either or both of these tests were not a common denominator in patients successfully treated.

TABLE V. FIFTY-FIVE FIVE-YEAR SURVIVORS
BRONCHOSCOPIC VERIFICATION

Total procedure	48*	
Biopsy positive	13	(27%)
Tumor seen only	6	(12%)
Negative	29	(60%)

*No bronchoscopic notation in 7 cases.

TABLE VI. FIFTY-FIVE FIVE-YEAR SURVIVORS (1946-1951)
VERIFICATION THROUGH CYTOLOGY

Cases examined	27	
Positive for tumor	15	(56%)
Atypical	8	(30%)
Negative	4	(14%)

There was nothing unusual about the pattern of tumor sites in this group. Right lungs were involved in 31 cases and left lungs in 24. Upper lobes were the site in 30 cases; lower and middle lobes in 19. Six tumors involved main-stem bronchi. Twenty-four were located centrally in the bronchial tree and twenty-eight were peripheral to main lobar bronchi. It was impossible to determine the exact point of origin in 3 cases.

More than one third of the five-year survivors were treated after the tumor had extended to mediastinal lymph nodes, chest wall, or pulmonary vein (Table VII). Therefore, the finding of spread beyond the confines of the lung was not a common factor limiting survival.*

TABLE VII. PRIMARY PULMONARY CARCINOMA
JUNE, 1932

EXTENT OF TUMOR RESECTED	FIVE-YEAR SURVIVORS (55)	ALL OTHERS (206)
Localized to lung	35 (64%)	67 (33%)
Mediastinal lymph node involvement	16 (29%)	50 (24%)
Gross extension	4 (7%)	89 (43%)

TABLE VIII. PRIMARY PULMONARY CARCINOMA
JUNE, 1932—MAY, 1951

EXTENT	CASES	FIVE-YEAR SURVIVORS
Localized to lung	102	35 (34%)
Mediastinal lymph node involvement	66	16 (24%)
Gross extension	93	4 (4%)
Total	261	55

*During the nineteen-year period under consideration, 34 per cent of resections for localized tumor resulted in five-year survival. Twenty-four per cent of cases with regional lymph node involvement and 4 per cent of cases with gross extension survived five years (Table VIII).

Patients who survived more than five years following resection had no common denominator in histologic pattern. The spectrum of cancer type in the survivor group was similar to that in all other cases diagnosed concurrently (Table IX). Thirty-eight of the cancers excised are recorded as epidermoid, and thirteen of these are listed as grade 3—the most malignant of epidermoid type. Adenocarcinomas totaled nine; two were well-differentiated, three were of simplex type (poorly differentiated adenocarcinoma), and four were bronchiolar adenocarcinomas. The remaining eight cancers were undifferentiated; five were of a large-cell type and three had some foci of epidermoid and simplex tumor.

TABLE IX. PRIMARY PULMONARY CARCINOMA
JUNE, 1932—MAY, 1951

HISTOLOGY	FIVE-YEAR SURVIVORS (55)	ALL OTHERS CLASSIFIED (486)
Epidermoid	38 (69%)	290 (60%)
Adenocarcinoma	9 (16%)	130 (27%)
Undifferentiated	8 (15%)	66 (13%)

COMMON DENOMINATORS

Chest x-ray abnormality stood out clearly as the first common denominator among the five-year cases. Every patient had an abnormal shadow on the chest film. The shadows appeared as rounded areas, segmental opacifications, and irregular densities—some with central radiolucency (Table X).

TABLE X. FIFTY-FIVE FIVE-YEAR SURVIVORS
X-RAY APPEARANCE

Rounded areas	33*
Density with central radiolucence	4
Irregular infiltrate	11†
Segmental or lobar opacity	7

*Six with added segmental or lobar opacity.
†One with emphysema, one with segmental opacity.

Although disturbed lung structures were demonstrated by x-ray, the diagnosis remained in doubt. This doubt, in many cases, contributed materially to the delay in treatment.

The average delay from initial manifestation to diagnosis was 6.7 months in cases who survived five years. In all others seen during the same period, the delay was 11.2 months (Table XI). Of the 7 cases discovered by survey chest x-ray, 3 had more than four months' delay prior to treatment (Table XII).

TABLE XI. PRIMARY PULMONARY CARCINOMA (JUNE, 1932—MAY, 1951)
AVERAGE DELAY

	INITIAL MANIFESTATION TO DIAGNOSIS (MONTHS)
Five-year survivors	6.7
All others	11.2
All other resections	11.5

TABLE XII. SEVEN SURVEY-DISCOVERED FIVE-YEAR SURVIVORS
DELAY TO TREATMENT

Less than 3 months	4
Five months	1
More than one year	2*

*Both were localized bronchiolar adenocarcinomas.

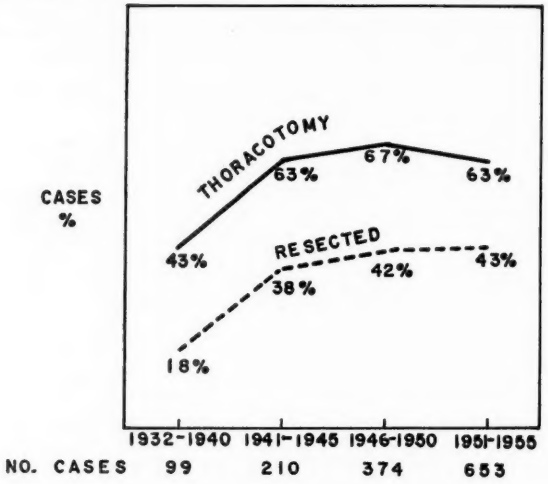

Fig. 2.

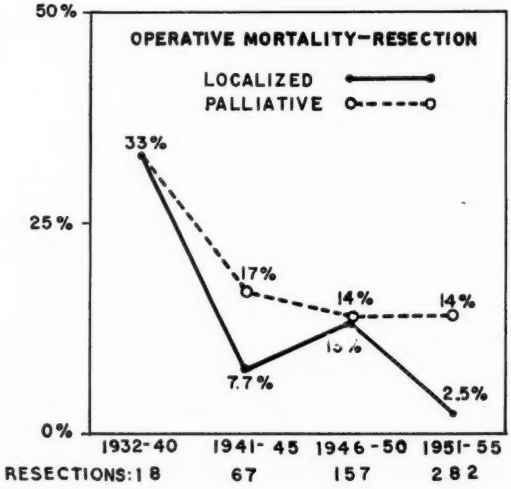

Fig. 3.

The second common denominator was that exploratory thoracotomy was employed to determine the true nature and extent of the shadow-producing lesion. In over one half of the cases, thoracotomy was the only method which provided material for histologic diagnosis.

The third, and last, common denominator was the application of surgical excision. Among cases treated by x-ray or chemotherapy, alone or in combination, there were no five-year survivors. Pneumonectomy with mediastinal

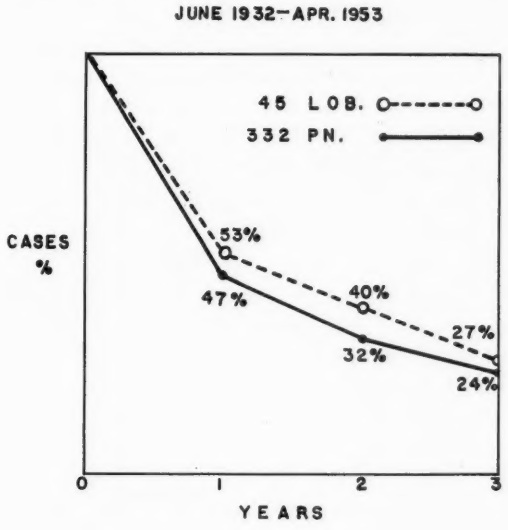

Fig. 4.

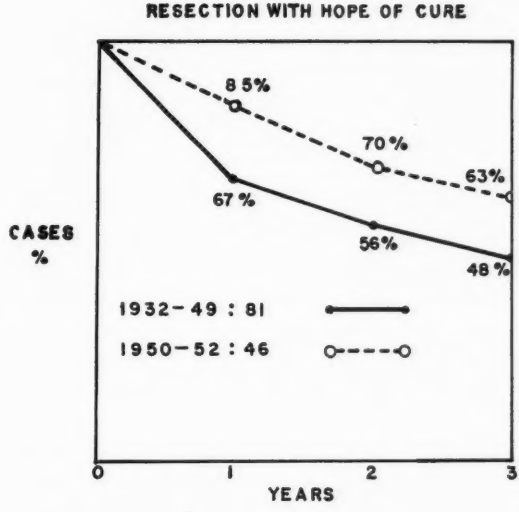

Fig. 5.

lymph node resection was performed in 51 cases. In one patient with epidermoid cancer, a block resection of chest wall (three-rib segments) was combined with a left upper lobectomy. One with carcinoma simplex had

a two-rib segment of the chest wall resected with the right upper lobe. In one, a left lower lobectomy was performed for bronchiolar adenocarcinoma. The fourth case, who was treated by less than total pneumonectomy, had a strictly circumscribed mass in the left upper lobe with all nodes negative. A total biopsy was obtained by apicoposterior segmentectomy. On frozen section, only inflammatory reaction was found. Subsequent pathologic examination revealed a small, localized, undifferentiated large-cell carcinoma in the wall of an abscess. Re-operation for a more liberal resection was advised but was refused.

MANAGEMENT

No common factors for survival appear in study of tumor and host characteristics. On the other hand, all common denominators pertain to case

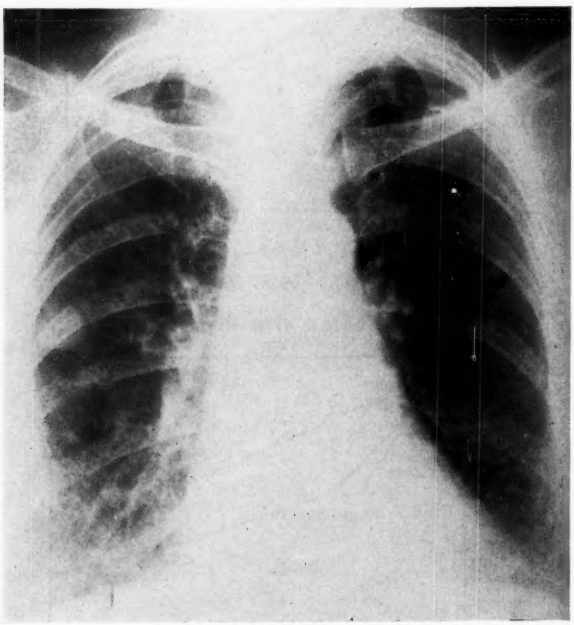

Fig. 6.—Mrs. S. M. R., 53 years of age. In the patient with an abnormal, isolated, peripheral x-ray shadow, management should proceed directly from x-ray evidence to exploratory thoracotomy. Bronchoscopy can be done immediately prior to insertion of the endotracheal tube for induction of anesthesia. This asymptomatic patient had pneumonectomy in December, 1949, following thoracotomy, biopsy, and a diagnosis of adenocarcinoma. Now, over six years later, she is well and active.

management. A simplified and more direct approach to individual problems has become possible as evidence has accumulated to indicate that x-ray, exploration, and resection are the only universal requirements for proper diagnosis and successful therapy of lung cancer.

An abnormal x-ray shadow is often the only evidence of the potential existence of cancer. The persistence of the discovery shadow should be verified by adequate, prompt radiologic study. Extended serial x-ray studies

unnecessarily add to delay and the dangers of tumor spread. Furthermore, negative bronchoscopy and cytology do not rule out the presence of cancer. The decision to explore should be made on the basis of an abnormal x-ray shadow alone. If peripheral metastases, precarious general condition, or associated disease do not contraindicate, exploration should be undertaken. In our clinic, bronchoscopy is performed immediately prior to the insertion of the intratracheal tube which is employed to administer the anesthetic for exploration.

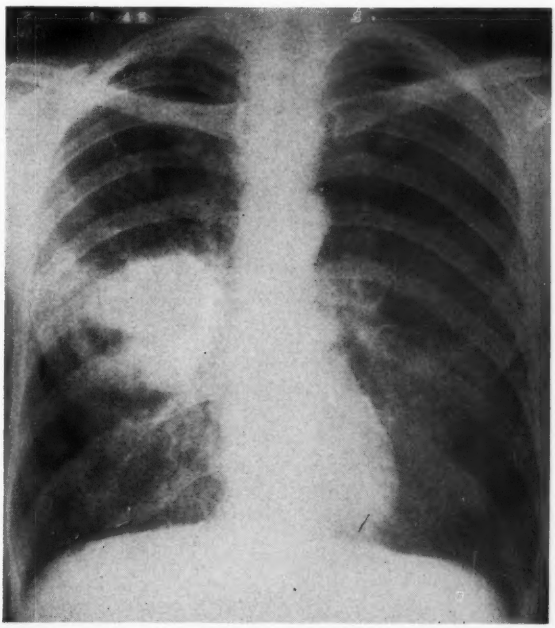

Fig. 7.—Mr. A. A., 42 years of age. In the patient with a large, abnormal x-ray shadow separated from the mediastinum by a clear area, the decision for exploratory thoracotomy can be made on the basis of the x-ray evidence. Bronchoscopy serves to determine the extent of intraluminal bronchial involvement and can be done immediately preceding anesthesia induction. This patient had a pneumonectomy in February, 1945, for epidermoid carcinoma, grade 2. He is alive and well now over ten years later.

The principal function of bronchoscopy in pulmonary cancer is to determine the integrity of the bronchial system to the sound lung. Occasional patients, who have clinical or x-ray evidence of mediastinal involvement, require bronchoscopic examination prior to decision for thoracotomy.

Exploratory thoracotomy gives access for histologic verification and for determination of tumor extent. All lymph nodes are resected with the dissection originating at the upper and lower limits of the mediastinum. If the lymph nodes are negative, a total biopsy is obtained by subsegmental, segmental, or lobar resection.

Safer resection is the result, to a significant degree, of earlier exploration. Through the years, as the exploration and resection rates have risen (Fig. 2), the mortality and morbidity have declined (Fig. 3). Most thoracic

surgeons have elected to employ radical pneumonectomy with or without extensive mediastinal lymph node dissection. However, in recent years, there has been increasing interest in lobectomy for selected cases. In our clinic, as the years have advanced, we have extended the completeness of lymph structure removal and have been more conservative of ipsilateral pulmonary lobes. There has been general agreement for limiting the resection to a lobe in the patient with low pulmonary reserve. Salvage studies suggest that other situations may call for limited resection. Lobectomy, if technically possible,

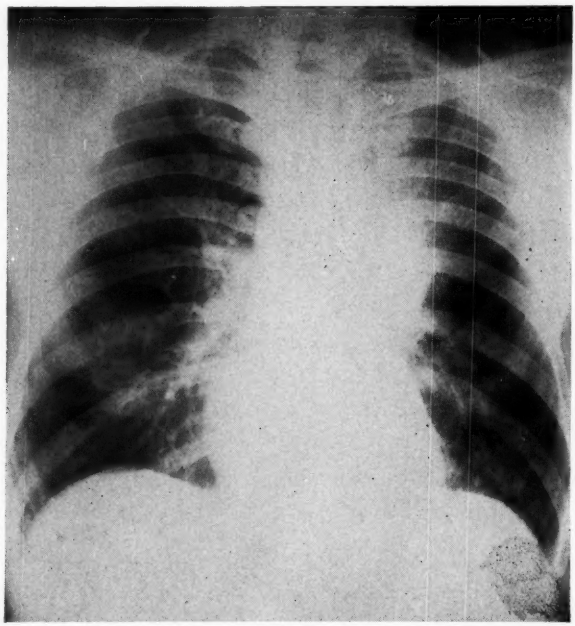

Fig. 8.—Mr. M. L., 50 years of age. When the abnormal x-ray shadow is in close proximity to the hilar region, bronchoscopy is necessary for evaluation of the bronchus to the sound lung. Since the feasibility of resection depends on the bronchoscopic findings, the decision for thoracotomy should await the results of bronchoscopy. In addition, supraclavicular lymph node biopsy can be of assistance. This patient's bronchoscopy permitted only visual examination of a tumor in the left upper lobe bronchus. On Oct. 16, 1948, a pneumonectomy was performed to excise an epidermoid carcinoma, grade 1, with metastases to two of twenty-seven lymph nodes. The patient is alive and well seven years later.

may provide better palliation than pneumonectomy when tumor must be left behind in vertebra, great vessels, heart, or contralateral mediastinum. In limited peripheral and "coin" type lesions with negative lymph nodes, a lobectomy will be just as all inclusive of the primary site as total pneumonectomy. Finally, in localized bronchiolar types, which include papillary adenocarcinoma and alveolar-cell tumors, lobectomy is clearly indicated because of their multicentric tendency. The site of subsequent origins cannot be predetermined. The next lesion may develop in the contralateral lung.

Three-year survival in 45 patients who underwent lobectomy between 1932 and 1953 has paralleled three-year survival of pneumonectomy patients

treated during the same period (Fig. 4). Since three-year survival following resection for lung cancer is almost as helpful prognostically as the five-year follow-up, the shorter period may be used as an effective indicator of therapeutic efficiency.

Comparison of three-year salvage of patients with localized lung cancer excised since January, 1950, with three-year salvage prior to that time, in the same type of case, gives substance to the feeling that definite progress is being made in surgical treatment (Fig. 5).

SUMMARY

No common factors for survival appear in the study of tumor and host characteristics. The few common denominators pertain to case management. There are but three:

1. All had chest films which revealed abnormal areas of density.

2. All required surgical exploration to determine the true nature of the shadow-producing lesion.

3. All were treated by excision of the cancer-bearing lung. Significant progress has been made in the prolongation of life for lung cancer victims. While we wait for the discovery of the cause and methods of prevention, further improvement in the salvage of victims is important. The focus of the management program should be on three ingredients essential for success: discovery (x-ray), verification (exploration), therapy (excision).

Discussion

DR. W. EMORY BURNETT, Philadelphia, Pa.—I want to thank the essayists for bringing us up to date on this still very important subject, and to add a few comments which corroborate to some degree what they have to say. Although at first, at the Temple University Hospital, we did lobectomy for cancer of the lung only as a compromise with risk, we were impressed by the marked conservation of function that occurred in these patients, and also by the apparent salvage. This lower mortality gave a great many more people a chance to survive a longer period. This was further bolstered by comments that have already been referred to, side remarks concerning lobectomy as a guilt-producing sort of procedure and, of course, the paper by Dr. Churchill which discussed radical lobectomy gave further support to the idea. Consequently, we have recently applied the rules of application which were outlined by Drs. Robinson and Jones, and found to our surprise that, in the more recent group of 362 cancer patients seen by us between 1948 and 1954, we had done 24 per cent of our resections as lobectomies with mediastinal dissection. Naturally, that is easier to do and more thoroughly accomplished from the right side than the left, but even the left side was dissected as far as possible. Of the five-year survivors of resection done in 1948, it was interesting that, out of 10 such patients, 3 of them had lobectomies; a small group but still of interest. In the earlier group, from 1936 to 1947, when we had considered and screened 429 patients for operability, pneumonectomy was done almost exclusively but there still was an occasional lobectomy. The five-year cures in that group were 4.2 per cent of the entire group considered but 32 per cent of the operated survivors; 24 per cent of these have lived more than five years, from six to fourteen years. It appears, then, from our data, that a tremendous majority of recurrences appear in the first two years postoperatively, and that those who pass that mark have about 70 per cent chance of reaching the five-year period. Second, that the patients without lymph node involvement have twice as good a chance to reach the five-year survival as do those with node involvement. But it was interesting that about one third of our five-year survivors did have lymph node involvement.

DR. CLAIR E. BASINGER, Grand Rapids, Mich.—Dr. Meade, Dr. Rasmussen, and I have recently reviewed our cases from 1948 to 1956. In 310 such cases studied, 54 pneumonectomies were performed and 6, or 11 per cent, of these individuals are still living at the end of three years. In comparison with lobectomies, 31 were performed and 6 of these individuals, or 20 per cent, are living three years or more afterward. Sixty-five of these resections, including both pneumonectomies and lobectomies, have had careful pathologic study. There were 38 of these with glands involved, of whom only 7 individuals, or 11 per cent, are still living. There were 27 without glandular involvement and there are still 20, or 31 per cent, of these individuals alive, 7 of them longer than three years.

I think this is a very timely review of an important surgical problem and a fine selection of papers.

DR. JOSEPH A. WEINBERG, Long Beach, Calif.—We have heard two very fine papers. I would like particularly to direct my remarks to the paper of Drs. Robinson and Jones. They have indicated that there is a great deal of confusion on the subject of indications for lobectomy in the treatment of cancer of the lung. In Taylor and Nathanson's excellent book on lymph node metastases, Dr. Churchill is quoted as saying that the surgical treatment of carcinoma of the lung today is comparable to the treatment of carcinoma of the breast by simple mastectomy without consideration for lymphatic spread. What we know essentially about the surgical treatment of carcinoma in general is that it calls for the thorough removal of the local lesion, together with the accessible regional lymphatics. This principle of surgical treatment applies to carcinoma of the lung just as much as it does to carcinoma in other locations—carcinoma of the bowel and carcinoma of the breast, for example.

It is true that there is much to be desired in the way of earlier diagnosis, but the possibilities of surgery have by no means been exhausted. As long as the treatment remains surgical, our hopes for improvement lie in the direction of improving the lymphatic dissection. We need not be greatly disturbed by the frequently mentioned fact that there are lymphatic cross-communications between the hemithoraces, a fact that is frequently cited by those who take a defeatist attitude on the value of lymph node resection. Actually, it is not rare to find at autopsies on patients dying of bronchiogenic carcinoma that the lesion has remained confined to the hemithorax in which it originated.

It is only by practicing thorough excision of the regional lymph nodes, together with pulmonary resection, that we can give the surgical treatment of pulmonary carcinoma the status of a cancer operation. Since the lymphatic dissection must necessarily be limited with lobectomy, this lesser procedure should be reserved for patients who are poorly suited for pneumonectomy because of the handicap of poor respiratory function.

DR. IRVING A. SAROT, New York, N. Y.—(This discussion was not returned. —EDITOR.)

DR. JAMES E. DAILEY, Houston, Texas.—I must confess that I too was guilty of doing lobectomies for carcinoma of the lung prior to 1950. Unfortunately, Dr. Robinson did not have the time to tell us his indications for these lobectomies so I would like to cite what I consider four indications or justifiable reasons for doing a lobectomy for carcinoma. *First,* in patients with a low pulmonary reserve, such as older individuals with considerable emphysema; *second,* in the patient with a small, isolated and peripherally located tumor nodule; a *third* indication would be a small, localized, bronchial carcinoma with local and hilar nodes apparently not involved with tumor; and *fourth,* the case where the thoracotomy has revealed extensive disease, grossly involved mediastinal nodes, or other structures and it is perfectly obvious that any resection would only result in palliation. This patient will surely die from distant metastases anyway, so there is no sense in sacrificing additional healthy lung. A local resection here may stave off or prevent a horrible excitus with vena caval obstruction, or at least it will abolish the distressing symptoms of cough and hemoptysis. With respect to node involvement, a frozen section biopsy will

often be helpful in differentiating inflammatory swelling from carcinoma. Furthermore, I feel that in most cases it is technically just as feasible to remove practically all the local hilar and mediastinal glands with lobectomy as it is with pneumonectomy.

(slide) In a survey of 111 patients with carcinoma operated upon between 1946 and including 1950, you see that 75 of these were resectable and 36 were nonresectable. Of those resected, 16 are still alive and well six to ten years after operation.

(slide) In the group of resections there were 16 lobectomies. Four of these, or 25 per cent, are still living and well.

(slide) I have illustrations of two cases of these lobectomies. This first one obviously cannot be classified as an isolated tumor or "coin lesion." The lower and middle lobes were removed in May, 1949, and he is completely well to date.

(slide) This second individual was in his late 60's and had what some might call a "coin lesion"—perhaps a "Texas dime."

(slide) A right lower lobectomy was performed on him in March, 1950, and he too shows no signs of cancer today, more than six years later.

So one should not really be too pessimistic with respect to attempting partial resections for cancer even though it might seem that the disease is quite far advanced.

DR. GABRIEL P. SELEY, New York, N. Y.—I also have been practicing lobectomy for carcinoma of the lung in selected cases. However, as a result of this experience I now feel very strongly that radical pneumonectomy is the operation of choice for carcinoma of the lung. Lobectomy should be practiced only if the patient cannot stand a pneumonectomy due to severe pulmonary insufficiency. Proper removal of the mediastinal lymphatics and nodes can be performed only with a pneumonectomy. By careful study of the surgical specimen it has been found that nodes close to the lobar hilus are often involved, and yet the mediastinal nodes, mediastinal contents, and paratracheal nodes have not as yet been invaded. This indicates that a curative procedure can be done by pneumonectomy when a lobectomy would only be palliative.

Nodes that appear normal can contain microscopic tumor cells. Morbidity and mortality figures should not be higher but, in fact, lower with pneumonectomy. Last, even a small lesion when situated near a fissure requires pneumonectomy or at least bilobectomy for proper local removal. I think it would be wrong to revert to lobectomy for carcinoma of the lung unless pneumonectomy is absolutely contraindicated.

DR. PAUL A. KIRSCHNER, New York, N. Y.—I would like to continue the discussion on the value of lobectomy in carcinoma of the lung. We too have felt that it has a prime place in the treatment of lung cancer, and at the Bronx Veterans Hospital our resident, Dr. Hamilton, has uncovered the following pertinent information: In an eight-year period, through January 1, 1954, we have performed a total of 113 resections; 24 lobectomies and 89 pneumonectomies. There has been no operative mortality in the lobectomy group, as compared to 16.9 per cent in the pneumonectomy group. One third of the lobectomy patients have survived at least two years, as compared with one quarter of the pneumonectomy patients. Of particular interest is that in a study of autopsy material on patients who have undergone resection, 7 in the lobectomy and 20 in the pneumonectomy group who have died at least three months following operation, the degree of local recurrence, which is a key factor in evaluating any cancer operation, was about the same; roughly 50 per cent. Conversely, 40 per cent of each autopsy group (although the lobectomy group is quite small) showed distant metastases without local recurrence.

We feel that lobectomy, properly applied, is as radical as pneumonectomy, and this, combined with its inherent low operative mortality rate and unquestioned better functional results, commends it for continued use in the surgery of cancer of the lung.

DR. LAWRENCE M. SHEFTS, San Antonio, Texas.—Our survival rates depend very definitely on our selection of patients to whom we offer surgery. This is especially true when results are given only on the ones operated on and not on total cases seen. Be that as it may, the main purpose (besides diagnostic) of many of our tests, such as scalene

node biopsy, is to help us determine to which cases we will offer surgery. As many of the audience here are doing scalene node biopsy for this purpose, I feel that it is important to determine whether it is correct to refuse surgery to the patients with scalene nodes positive for cancer. We have, with the experience of over 320 scalene node biopsies for a large variety of lesions, been refusing surgery when the nodes were positive for carcinoma of the lung. I know, from talking with many, that this has also been in the main the general practice. I question whether this practice is a correct one in all cases. When we stop and think of the cases shown here, some very probably had mediastinal node involvement and, knowing the mediastinum does not lend itself to block dissection, we may expect that some of the cases in these survival groups had, and may have, remaining mediastinal node involvement. In these cases the scalene nodes may well have been positive for carcinoma. Therefore, possibly in refusing operation to some of these patients (particularly those with small isolated lesions) with positive scalene nodes, we may be acting incorrectly. Actually, in a sense, therefore, it would possibly be better not to use scalene node biopsies as a criterion of whether surgery should or should not be done. The use of a positive scalene node, in the aged or in instances of severe cardiorenal disease, to excuse our not operating is understandable and probably correct, but to use it as a blanket reason for refusing surgery may, though it gives one excellent survival rates, result in missing the few that might have been given prolongation of life. I doubt if anyone here, during exploration of a bronchiogenic carcinoma, decides not to do a resection merely because there is mediastinal node involvement. If it is technically resectable, it is resected. Yet we know from experience that a respectable percentage of such cases may well have positive scalene nodes.

DR. RICHARD H. MEADE, Grand Rapids, Mich.—The question has been asked: "Could you ask the authors if they ever performed resections if the biopsies were positive?" I presume he means if you cannot feel the glands in the neck, doing just a routine scalene biopsy.

DR. ROBINSON (Closing).—I want to thank the discussants. I feel that our main purpose in presenting this paper has been accomplished, namely, to make it clear that the members of this Association have accepted as a "respectable member of the family" lobectomy for the surgical treatment of certain patients with carcinoma of the lung.

DR. OVERHOLT (Closing).—In answer to the single question, I should say that we have, in a few instances, elected to do a resection in the presence of positive cervical nodes. Two thirds of the lymph structures within the mediastinum are accessible at thoracotomy. Cervical nodes are also within the surgical field. It is too early to know if it is possible to prolong lives by that method or not.

As to lobectomy versus pneumonectomy, I wish to say that we may clarify and simplify the surgical approach, but it is never wise to set hard-and-fast rules. So it is with the extent of the resection for cancer. It depends on circumstances presented by each case.

I should like to show two slides which indicate our own experience with regard to lobectomy. We have gradually elected to limit the resection in more and more cases. The first slide gives the relative percentage of total resections to lobectomy in the period from 1932 to 1950. Then, only 6 per cent of the resections were limited to the lobe. In the past five years, we have performed lobectomy in one third of all the cases. The next slide shows three-year salvage rates as to the extent of the resection. The over-all salvage by lobectomy was 27 per cent in contrast to 24 per cent for pneumonectomy. The cases selected from the two groups are not comparable since the more extensive lesions required the more radical resection. The fact that a substantial number of cases of cancer of the lung, if properly selected, may be salvaged by a more limited resection, is heartening.

TWO UNUSUAL CONGENITAL ANOMALIES OF THE THORAX: (1) SUPERNUMERARY RIBS AND (2) ABNORMAL INTRATHORACIC FASCIAL BAND

Review of Literature

John K. Stevenson, M.D., and K. Alvin Merendino, M.D.
Seattle, Wash.

APPROXIMATELY one per cent of persons have some variation from the normal pattern of 12 pairs of thoracic ribs. The majority of these will have extra ribs in either the cervical or lumbar region. These may be single (20 per cent) or paired (80 per cent). In the unilateral minority they are more common on the left side (60 per cent).[1, 2] Bifid or forked ribs are not rare and frequent reports appear in the literature. Not infrequently, one will find one side of the thorax with fewer than 12 ribs.[3, 4]

Careful search of the literature revealed only two previous case reports of supernumerary thoracic ribs.[5, 6] No account was found in which the diaphragm was attached to these ribs. Two case reports were found in which there were abnormal intrathoracic muscle bundles or fascial bands.[7, 8]

To the surgeon or anatomist, minor congenital or developmental defects of the human body are common and are usually accepted as normal species variation. Occasionally, one encounters a more unusual variation or anomaly which stimulates more than the usual interest or concern and, in the case of surgery, requires a change in operative approach or surgical correction. Rarely does one encounter a variation from the normal which is completely unsuspected and not previously reported. This report deals with two such instances.

CASE REPORTS

Case 1.—R. M. N., a 17-year-old schoolgirl of American Indian and Irish extraction, was referred to the Surgical Department of the King County Hospital with a diagnosis of asymptomatic atelectasis of the lower lobe of the right lung. There was a previous history of pulmonary tuberculosis on the right side for which she had been hospitalized for two years beginning at the age of five.

She had been well and asymptomatic until March, 1955, when she collapsed at school and was taken to her private physician for examination. An x-ray of the chest showed a shadow of a solid opacity on the right extending from the seventh rib down in a triangular fashion from the hilus to the lateral edge of the diaphragm. Further diagnostic studies, completed at the King County Hospital, including bronchoscopy, bronchograms, and multiple roentgenograms of various views, failed to establish a firm diagnosis (Figs. 1, 2, and 3).

Three "accessory" ribs on the right at the level of the seventh cervical vertebra, and at the level of the sixth and seventh thoracic vertebrae, were demonstrated and it was felt that they had some bearing on the peculiar shadow in the roentgenograms. It was suspected

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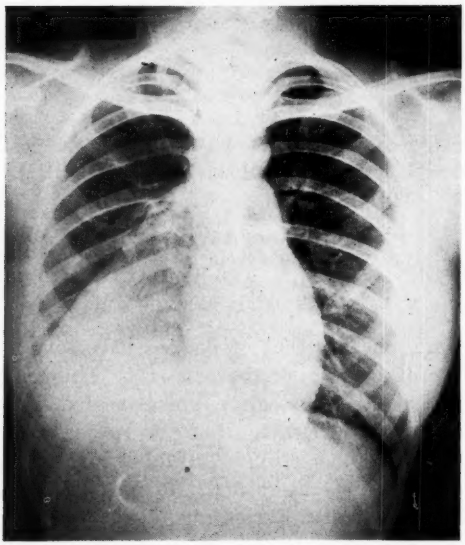

Fig. 1.

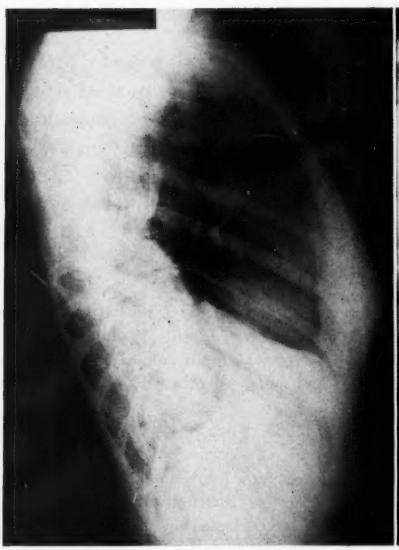

Fig. 2.

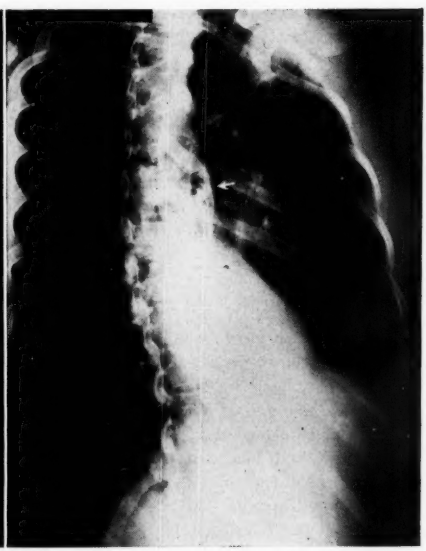

Fig. 3.

Figs. 1 and 2.—Routine posteroanterior and lateral x-ray views of the chest in Case 1 showing the supernumerary ribs C-7, T-6, T-7 on the right with the triangular shadow extending from the level at the sixth thoracic vertebra at the hilus to the base at the lateral thoracic wall.

Fig. 3.—Right anterior oblique x-ray view with higher peak kilovoltage to increase rib detail. The two supernumerary thoracic ribs at the level of the sixth and seventh thoracic vertebrae are seen at the apex of the triangular density.

that this shadow represented an extrapulmonic condition. In April, 1955, the patient was subjected to a right posterolateral exploratory thoracotomy with the following findings:

Ribs: The cervical rib on the right could not be palpated or demonstrated at the time of surgery. The "accessory" ribs located at the level of the sixth and seventh thoracic vertebrae extended from their articulation on the vertebral column ventral and slightly caudal to the normal rib articulation. They extended downward and ventrally for a distance of 8 and 11 cm., respectively, and at their termination projected into the thoracic cavity, a distance of 1.5 and 2 cm. beyond the normal wall contour. Their exposed surfaces were covered normally with parietal pleura.

Diaphragm: There was attachment of the diaphragm to the medioventral surfaces of the previously described "accessory" ribs at the level of the sixth and seventh thoracic vertebrae at the vertebral column. From this attachment it extended downward and outward in the form of half a cone to a normal peripheral attachment at the base. It was assumed that this abnormal "tenting" of the diaphragm accounted for the abnormal x-ray findings previously described (Fig. 4).

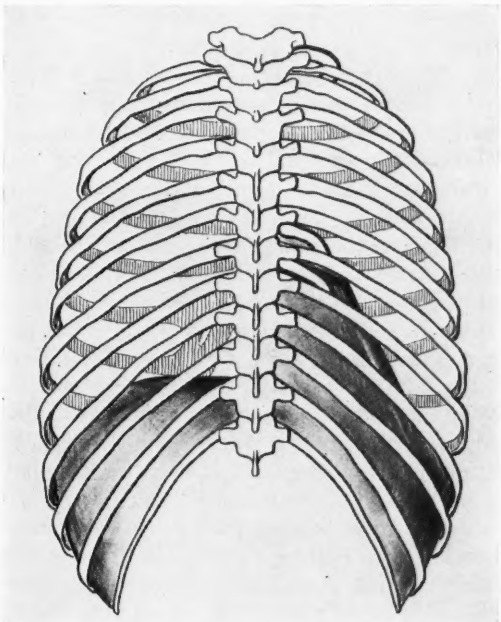

Fig. 4.—Diagrammatic drawing (posterior view) of Case 1, illustrating more clearly the position of the diaphragm and its attachment to the supernumerary ribs on the right. The cervical rib also is indicated.

Lungs.—There was no abnormality found except for indentation at the posteromedial surface of the right lower lobe to accommodate the diaphragmatic "tent."

A small incision in the diaphragm established the relatively normal relationship of the liver below. The phrenic nerve on this side entered the diaphragm adjacent to the pericardial attachment but more dorsal and cephalad due to the elevation, as would be expected. The wound was closed and the patient returned to the hospital ward where she had a completely uneventful postoperative recovery. The patient was discharged to her home on the eighth postoperative day.

Following operation, x-ray films that had been taken in 1944 were now made available to us. They demonstrated essentially the same findings as were seen on our preoperative x-rays.

Comment.—The combination of the related anomalous development of the ribs and diaphragm might be explained as follows:

At the stage of development of the embryo, when the cephalad and caudad halves of adjacent sclerotomes unite in new combinations to form the primordia of the definitive vertebras, the ventral processes extend laterally into the thoracic wall, giving rise to the primitive ribs. Failure of the component halves of the ventral process of the embryo vertebras to unite as its dorsal process does, would result in two projections extending laterally in that particular space giving rise to two ribs. The dorsal or neural process develops peduncular, transverse, anterior and posterior articular and laminar processes. At this stage, the transverse process lies at a considerable distance from its corresponding rib. The developing ribs meet the outgrowing transverse process, form joints and are invested with their ligaments. Thus, the formation of a twinned rib bud as just described allows two ribs to articulate with one transverse process and vertebral body.[9, 10]

Concurrently, beginning at the level of the highest occipital sclerotome, the septum transversum is undergoing its extensive caudal migration as a result of a faster forward growth of the dorsal body which leaves the ventral structures behind. The common cardinal veins, on their way to the heart, curve around the bilateral pleural canals laterally in the somatic body wall. As these veins shift toward the midline, they carry out a mesentery-like fold, the pleural pericardial membrane, from the pulmonary ridge. Opposite the fourth cervical vertebra, the septum transversum receives the phrenic nerve by way of the pleural pericardial membrane. During this descent the lungs begin to develop in the pulmonary ridge and soon bulge into the bilateral pleural canals. At first there is only a shallow, narrow space between the pulmonary ridge located cranially and a dorsal-lateral extension of the caudal portion of the septum transversum. When the lung can expand caudad or laterally only by invading the adjoining body wall, this small space is enlarged, forming the pleural-peritoneal component of the diaphragm bilaterally by drawing out a shelf of tissue from the caudal portion of the pulmonary ridge. Growth of the lung and shifting of the liver and common cardinal veins create more room between these pleural boundaries. Continued expansion of the pleural cavities progressively increases the area of this membrane, pulling with it a component or extension of the somatic body wall.[11] It is likely that the anomalous attachment of the diaphragm to "accessory" ribs described can be accounted for by failure of release of the descending dorsal portion from the body wall.

When the diaphragm reaches its final location during the second month, the ventral attachment of septum transversum is at the level of the first lumbar segment. With the dorsal medial component (the pleuroperitoneal membrane) and the component of the somatic body wall attached at the level of the sixth and seventh thoracic vertebrae, the peculiar anatomic variation presented here would result.

CASE 2.—G. H., a 39-year-old white man, was referred to the Thoracic Surgical Service of the King County Hospital with the diagnosis of symptomatic mitral stenosis. There was a previous history of rheumatic fever with chorea at 9 to 11 years of age, with the first awareness of a heart murmur a few years later. He was free of symptoms until about five years prior to

his referral here when he first became aware of dyspnea and fatigue on exertion. This progressed to the point where he could not work but was able to meet his ordinary daily activities without difficulty.

Diagnostic studies and evaluation indicated that the patient would be clinically and symptomatically benefited by surgical correction of the mitral stenosis. He was admitted to the hospital in November, 1954. Mitral commissurotomy was performed through a left lateral incision. As an incidental finding there was a very firm, hard tendinous band approxi-

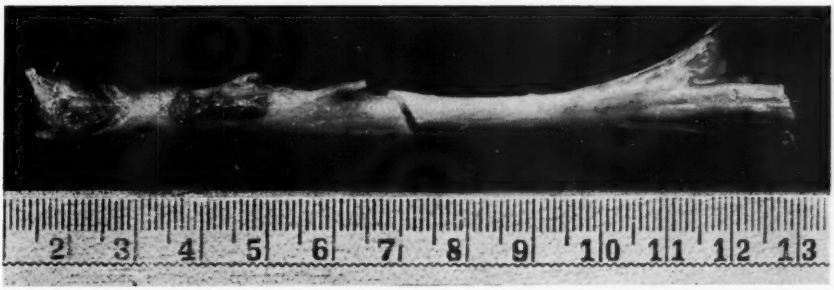

Fig. 5.—Photograph of the intrathoracic tendinous band which extended from the second rib to the dome of the diaphragm in the patient in Case 2. Histologically, the specimen was thought to be tendon.

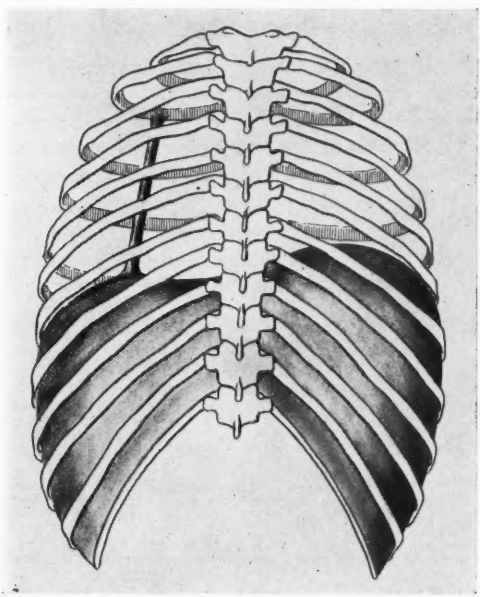

Fig. 6.—Diagrammatic drawing illustrating the position and attachments of the tendinous band removed from the patient in Case 2 and pictured in Fig. 5.

mately 1.5 cm. in diameter and 14 cm. long, extending from the apex of the thoracic space from its apparent attachment to the undersurface of the second rib anteriorly down to the tendinous central portion of the dome of the left hemidiaphragm. This tendinous structure was completely circumscribed by invaginated lung and covered by visceral pleura. There was relatively complete fixation of the left hemidiaphragm due to this tendinous attachment. The structure

was excised, releasing the diaphragm, and the operative wound closed (Figs. 5 and 6). The patient's postoperative course was uneventful and he was discharged to his home on the tenth postoperative day and has since returned to work.

Comment.—Microscopic sections of this fibrinous band showed it to be almost completely acellular with hyalinization of fibers, producing in many areas homogenization so that evaluation of architecture was impossible. However, the over-all structure resembled old hyalinized tendon exhibiting focal areas of calcification. It was impossible to detect whether or not the tendinous structure actually terminated at its apparent attachment to the second rib or extended into the neck to the level of the third or fourth cervical vertebra. Probably, this structure remained as an unresolved remnant of the cranial-dorsal attachment of the septum transversum on the left. It was extended into the configuration found by the process of growth and development described above.

The fact that the fibrous tendinous band described was not demonstrated by chest x-ray would account for its not being discovered earlier.

REVIEW OF LITERATURE

Because of the relatively rare occurrence of such cases and the similarity to the two cases reported here, other cases previously reported will be reviewed (Table I). Although they are not completely similar to the two reported here, their abnormal embryologic development can be explained on the same basis.

TABLE I. REVIEW OF LITERATURE

CASE	SEX	AGE	RACE	SIDE	RIBS	PLEURAL SPACE
Marbut, and DeGinder	F	20	White	Rt.	Supernumerary T-6	Normal
Jacobs	M	43	Negro	Rt.	Supernumerary T-3	Normal
Stevenson, and Merendino	F	17	American Indian	Rt.	Supernumerary C-7, T-6, T-7	Dorsal medial portion of right hemidiaphragm attached to supernumerary thoracic ribs
Allen	M	60	Negro	Rt.	Normal	Two transpleural muscles from sixth thoracic rib to dome of diaphragm
Lutz	F	25	White	Rt.	Incomplete and bifid fourth thoracic rib	Fibrous band from tip of rib to the diaphragm
Stevenson, and Merendino	M	39	White	Lt.	Normal	Tendinous band from anterior surface of second thoracic rib to dome of diaphragm

Marbut and DeGinder (1953)[6] reported the finding of a complete supernumerary, intrathoracic rib in a 20-year-old woman. The rib articulated with the right anterior margins of the sixth and seventh vertebral bodies at the interspace and extended caudally, well within the posterior thoracic wall, and was surrounded by normal lung and visceral and parietal pleura.

Jacobs (1949)[5] reported a supernumerary rib in a 43-year-old Negro. This rib originated from the third dorsal vertebra on its anterolateral surface on the

right, articulating independently of the normal rib arising from this vertebra. The rib coursed along the posterior thoracic wall downward and slightly lateral on the anterior surface of the normal ribs, external to the pleura. It terminated at the level of the eighth thoracic vertebra, 7 cm. from the vertebral body. There were 12 pairs of thoracic ribs arising in a normal manner.

In 1947, Lutz[7] reported the finding in a 25-year-old girl of an incomplete bifid fourth thoracic rib on the right side. The rib did not articulate with the sternum and was inset medially as compared to the normal thoracic cage. Covered with parietal pleura, it projected into the thoracic cage. The inferior projection of the fork extended dorsally and caudad to the level of the eighth interspace, approximately 8 cm. from the vertebral column. A fibrous band extended down from the tip of this lower extension of the rib to the diaphragm.

Allen[8] reported, in 1950, a case in which he described finding, in a 60-year-old Negro, two transpleural muscles lying in the oblique fissure of the right lung. The medial muscle arose from the sixth rib 1 inch from the vertebral column and inserted into the central tendon just behind the caval opening. The lateral muscle took origin from the sixth rib 3 inches from the vertebral column and inserted into the extreme lateral aspect of the central tendon.

It is likely that this anomalous finding is closely related to that of our first case in that these transpleural muscles arise from the component from the pleuroperitoneal membrane and/or its component from the somatic body wall.

SUMMARY AND CONCLUSIONS

1. Two unusual congenital anomalies of the chest are reported.
2. An embryologic basis for their occurrence is considered.
3. Similar congenital abnormalities previously reported are reviewed.
4. Even though the congenital anomalies described were incidental and asymptomatic, they were of clinical significance. It should be recognized that these variations do exist and can present difficult diagnostic problems.

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PNEUMONECTOMY FOR PULMONARY TUBERCULOSIS

An Analysis of 151 Cases

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NO attempt has been made in this paper to compare the results obtained in pneumonectomy for pulmonary tuberculosis with those reported in the literature. Materials of pulmonary tuberculosis are often composed of cases with a different degree of severity which influences the results. It is therefore considered of more value to report one group and discuss the pathophysiologic problems arising in the surgical treatment of "bad risk" patients undergoing pneumonectomy for pulmonary tuberculosis.

MATERIAL

Many patients undergoing a pneumonectomy for pulmonary tuberculosis are in a really bad condition. They may be toxic, having had fever, with considerable expectoration, for several months. The respiratory reserve is usually very small due to disease of the only functioning lung or residues after a previous pneumothorax. One patient has had pneumonectomy performed during contralateral pneumothorax treatment.

Of the 151 patients operated upon, 16 are dead and 111 have been followed up for one to five years or more. Twenty-two patients were excluded as the observation time was less than one year. Two patients could not be traced.

Age.—Old age is no contraindication for the removal of a destroyed lung. The oldest patient in this material was a 64-year-old woman. She withstood a right extrapleural pneumonectomy and later a 10-rib thoracoplasty in two stages very well and her sputum and gastric washings one year later were negative to guinea pig tests. The youngest patient was an 11-year-old girl

Table I. Age and Sex Distribution in 151 Patients Undergoing Pneumonectomy for Pulmonary Tuberculosis

AGE	MEN	WOMEN	TOTAL
10-19	1	1	2
20-29	8	15	23
30-39	25	34	59
40-49	19	21	40
50-59	13	13	26
60-69	0	1	1
Total	66	85	151

From Sabbatsberg Hospital: Surgeon-in-Chief, C. Crafoord, M.D., Professor—St. Göran Hospital: Physician-in-Chief, A. Westergren, M.D., Professor—Söderby Hospital: Physician-in-Chief, T. Bruce, M.D., Docent.

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who underwent a left pneumonectomy without any space-diminishing procedure. The age and sex distribution are shown in Table I and Fig. 1.

INDICATIONS FOR PNEUMONECTOMY

A. Indications Due to Pathology.—A pneumonectomy is usually performed only when the lung is destroyed by tuberculosis.

1. Stenosis of the main bronchus: In 37 cases, i.e., 25 per cent, there was a stenosis of the main bronchus. This finding in itself is no absolute indication for a pneumonectomy. It is the combination of a destroyed lung with a stenosis of the main bronchus that makes it necessary to remove the whole lung. If some part of the lung parenchyma is without pathologic changes, it may be saved. Then a bronchography has to be done in order to outline the length of the stenosis and to exclude the possibility of bronchiectasis behind the stenosis. In this material, it has been possible in 6 patients to do a resection of the main bronchus and a bronchotracheal or bronchial anastomosis.

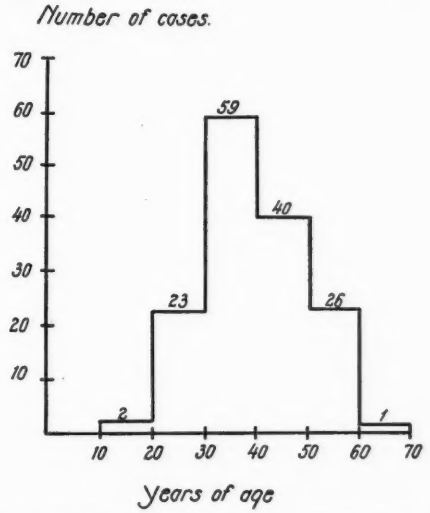

Fig. 1.—Age distribution in 151 cases of pneumonectomy for tuberculosis.

In 2, it was possible, after division of the 4 upper pairs of intercostal arteries and mobilization of the aorta, to anastomose the left lower lobe bronchus to the trachea. Most patients coming to surgery, however, already have a destroyed lung behind the stenosis.

A bronchial stenosis may be due to (1) endobronchial tuberculosis or (2) peribronchial tuberculous glands, or both. In most cases, it is difficult at the time of operation to evaluate the importance of each factor. In 5 patients, a number of calcified glands were found constricting and compressing the main bronchus. In the 10 patients, in whom endobronchial tuberculosis was the main cause of the bronchial stenosis, it was often necessary to spend a considerable time separating the main bronchus from the pulmonary artery. In

some of these cases, it has been necessary to do this separation with a knife. The bronchus and the pulmonary artery seem to be grown together by a very dense fibrotic tissue and no glands are found in the stenotic area.

The left main bronchus was stenosed more often (31 cases) than the right main bronchus (6 cases—see Fig. 2). This is probably due mainly to the fact that the left main bronchus is much longer (5 cm.) than the right one (2 cm.). This is the only group of cases where there has been a dominating incidence of the left lung. In the other groups, there has been roughly an equal side distribution.

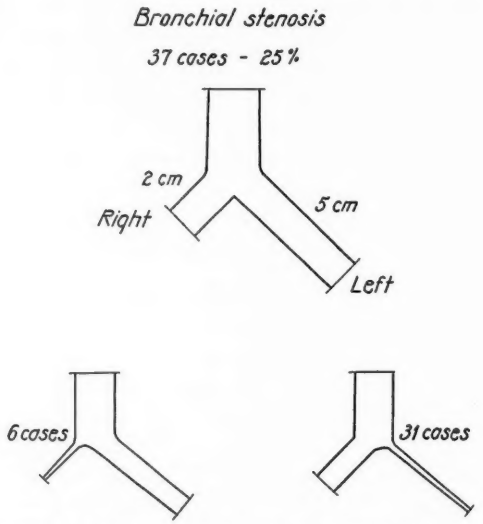

Fig. 2.—There is a dominating incidence of left-sided bronchial stenosis.

2. Tuberculous cavitation (destroyed lung): The most common indication for a pneumonectomy was a destroyed lung with a number of cavities. In 19 of these cases there was a lobar bronchial stenosis as well. Some patients also had cavitation in the remaining lobe after a lobectomy (6 cases), and the combination of pulmonary tuberculosis and empyema (15 cases). In the group with empyema, 9 patients had a bronchopleural fistula before the operation. In several patients with empyema sent for an extrapleural pneumonectomy, it has, however, been possible to save the entire lung or part of it. Of the whole group of 151 cases, 101 or two thirds of the material were extrapleural resections. Most of these patients had a calcified fibrothorax needing considerable effort to free it.

B. Indication Due to Pathophysiology.—In cases where, from the x-ray investigations alone, it was difficult to decide whether a pneumonectomy should be performed or whether some segments should be left, bronchospirometry is the most important function test. The following principle has then been used in my cases: If the bronchospirometry shows an oxygen uptake of 10 per cent

or less on the side to be operated on and the operation is not in itself expected to improve the function considerably (by decortication or bronchial anastomosis), a pneumonectomy is performed. Early in this series, a ventilating emphysematous lobe with minimal function but without active tuberculosis was left in some instances (instead of doing a pneumonectomy at once). By leaving this plomb of nonfunctioning lung tissue, a much smaller thoracoplasty had to be done. At follow-up, however, a reactivation has been found in the "lung plomb" in several cases. There is practically no advantage in leaving a functionless lobe. Only a negligible amount of blood passes through its pulmonary artery. Therefore, pulmonary hypertension cannot be prevented by leaving nonfunctioning lung tissue. On the other hand, it is a disadvantage to leave nonfunctioning lung tissue, thereby increasing the dead space, and, when such a lobe has been the source of a positive sputum, it has to be removed at a new operation.

If the bronchospirometry shows 20 per cent or more of the oxygen uptake on the side to be operated on, every effort is made to save as much functioning lung tissue as possible at the resection. In cases having between 10 and 20 per cent of the oxygen uptake on the side to be operated on, it is often possible to save some part of the lung (usually the basal segments). The final decision has then to be made during the operation and often after considerable time has been spent on a decortication. In the presence of contralateral disease, as many segments as possible are left behind.

PREOPERATIVE INVESTIGATION OF LUNG FUNCTION

The most important information regarding the pulmonary function is obtained by a study of all x-ray films from the beginning of the disease. The maximal movements of each diaphragm are recorded also.

A. The Maximal Breathing Capacity.—The maximal breathing capacity (MBC) was then recorded. The lowest preoperative value for MBC was 19 L./min. The patient, a 37-year-old man, withstood an extrapleural pneumonectomy and later a total thoracoplasty and the sputum and gastric washings were negative to guinea pig tests one year later when the MBC was 18 L./min. (see Figs. 8*A* and 8*B*). Fifty per cent of the tested male patients had a preoperative value of less than 69 L./min. Fifty per cent of the female patients had a preoperative MBC of less than 49 L./min., 6 having an MBC between 20 and 29 L./min.

B. The Vital Capacity (VC).—The lowest preoperative value of vital capacity for men was 1.1 L. with 50 per cent of the patients below 2.6 L. The lowest value for women was 1.1 L. with 50 per cent of the cases with values for VC below 2.0 L.

C. The Bronchospirometry.—A bronchospirometry was performed only in 49 cases, where it was difficult to decide if some part of the lung could be left. Thirty of these patients had an oxygen uptake of less than 10 per cent on the side to be operated on (21 had less than 5 per cent). Thirteen patients had an oxygen uptake of between 10 and 20 per cent and only 6 had more than 20

per cent on the side to be operated on. In several instances, where a very low oxygen uptake was found, but where a significant increase of the oxygen uptake of that lung was found when placed lowermost with the patient in the lateral position, it was possible to save lung tissue after a decortication. Then the thickened pleura was greatly responsible for the impaired function.

D. The Residual Capacity.—The residual capacity was investigated in 81 cases and was below 35 per cent of the total capacity in 63 cases, between 35 and 40 per cent in 8, between 40 and 45 per cent in 7, and above 45 per cent in 3.

E. The Pulmonary Artery Pressure.—The pulmonary artery pressure was investigated in 15 cases before operation and in 12 cases during the operation. Nine patients had a mean pressure at rest or during operation of more than 20 mm. Hg. Of these, 1 patient, with 29 mm. Hg resting pressure, needed tracheostomy and 3 patients with 22, 23.5, and 27 mm. Hg mean pressure needed tracheostomy with prolonged artificial ventilation. Five patients with a mean pulmonary artery pressure of 21, 23, 25, 29, and 37 mm. Hg had an uncomplicated immediate postoperative course. The patient with a pressure of 37 mm. Hg died later on after an infection with bronchial fistula. Two patients with 17 and 19 mm. Hg mean pressure have later died in cor pulmonale. It therefore seems to be difficult to draw any conclusion from the pulmonary artery pressure in regard to the operative risk, at least from this material.

METHOD OF TREATMENT

Only in 1 patient, a girl of 11 years of age, has a space-diminishing procedure been omitted. Otherwise, it has been felt important to obliterate the space for the following two reasons: (1) to diminish the risk of infection with an eventual bronchial fistula, and (2) to keep the mediastinum as close as possible to the midline to prevent overdistention of the remaining lung with emphysema, and lessen the risk of reactivation of tuberculosis.

In this material, there has been a change, from a procedure in several stages where first the thoracoplasty preceded the resection, to one-stage operation with an osteoplastic wall thoracoplasty.

1. In a group of 49 patients, a curative thoracoplasty was first performed in 2, 3, or 4 stages. After a period of from one to ten years, the pneumonectomy was performed after the thoracoplasty was considered a failure.

2. In a group of 47 patients in whom a pneumonectomy was indicated, a first-stage 5-rib (or 3-rib) thoracoplasty with apicolysis was performed. After some months, the pneumonectomy was performed and the rib resection was extended down to include the ninth rib on the left side and the tenth rib on the right side. One 28-year-old man in the group, with a giant cavity in the right upper lobe, had a spread to the left lower lobe after the first-stage thoracoplasty. The pneumonectomy was performed after one year but at follow-up there was a tuberculous cavity surrounded by tuberculosis in the basal segments of the left lower lobe. This method is now abandoned in favor of the one-stage procedure. In some cases where a 5-rib thoracoplasty had

been performed as a preliminary operation, the diaphragm was mobilized and resutured at a higher level, i.e., to the fifth intercostal muscle bundle after the pneumonectomy instead of an extended rib resection. It is doubtful if much is to be gained by this procedure as compared to a phrenic crush.

Fig. 3A.—The mediastinum is kept in the midline one year after an osteoplastic wall thoracoplasty.

3. In a group of 17 patients, the pneumonectomy was performed as the first operation and a total thoracoplasty at a later date; in one stage in 12 cases, and in two stages in 5 cases. A total thoracoplasty, sometime after a pneumonectomy, is a very well-tolerated procedure and need usually not be divided into two stages.

4. To achieve a one-stage procedure, a plastic plombe (Polystan) was introduced intrapleurally in 7 instances and extraperiosteally in 5, after com-

pletion of the pneumonectomy. Only patients were chosen in whom there was considered to be no danger of infection. At the follow-up after one year there has been no untoward effect of the plombe.

5. In 4 cases, a total thoracoplasty with rib resection was performed at the same stage as the pneumonectomy. Only patients in a very good condition were chosen.

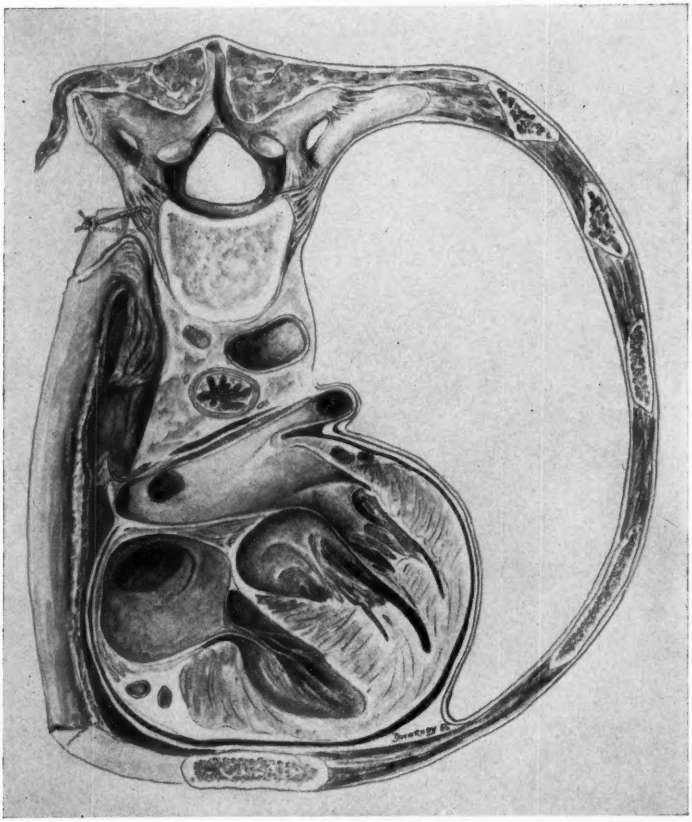

Fig. 3*B*.—The posterior ends of the ribs, bent or fractured in the costal cartilages, are fixed to the vertebral bodies through the costovertebral ligament behind the rib by nylon threads. (From Björk.[4])

6. In order to prevent the paradoxical movement of the mediastinum in the postoperative period and to prevent a later mediastinal shift to the side operated upon, an osteoplastic wall thoracoplasty has been worked out and applied in 21 cases. With this method, we have a one-stage procedure which can be applied to patients with a very limited respiratory function and with tuberculous empyema. In 13 of the patients in this group, an extrapleural pneumonectomy had to be performed. There was only one complication with infection. Five patients in this group needed prolonged artificial ventilation

through a tracheostomy during the postoperative period. The method includes most often a resection of the first rib and posterior parts of ribs 2 to 9 on the left side and 2 to 10 on the right side. Then the posterior ends of the ribs, bent or fractured in the costal cartilages, are fixed to the vertebral bodies through the costovertebral ligament by nylon threads through drill holes in the posterior ends of the ribs. Thus, the mediastinum is kept in the midline for the future (see Figs. 3*A* and 3*B*).

From a technical point of view, I recommend a one-stage procedure with an osteoplastic wall thoracoplasty after pneumonectomy for tuberculosis. The bronchus is cut at a level a few millimeters below carina, even on the left side. The bronchus is closed with isolated terminal sutures of chromic catgut on an Atraumatic needle and covered with mediastinal pleura. Some streptomycin crystals are placed under the pleural flap.

RESULTS

Dead.—Of the 151 patients, 16 are dead. In the group of 101 patients with extrapleural resection, 14 were lost (14 per cent); in the group of 50 patients with intrapleural resection, 2 cases or 4 per cent were lost (Figs. 4 and 5).

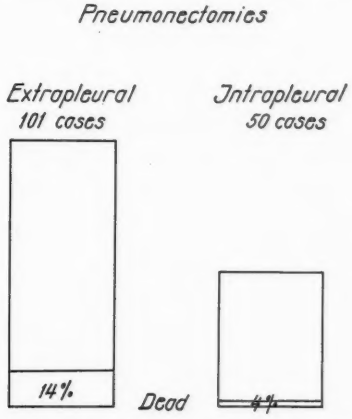

Fig. 4.—Fourteen per cent were dead in the group in which extrapleural pneumonectomies had to be performed. Only 4 per cent died in the group of patients who had had intrapleural pneumonectomy. The mortality percentage will reflect the difference in severity of disease in the two groups.

Five patients died within one week of the operation: Two patients never regained consciousness after operation (1 had a massive spillover, the other went into pulmonary edema due to cor pulmonale). One patient died after thirty-two hours with liver necrosis due to chloroform anesthesia. One patient (44 years old) died after thirty-two hours in ventilatory insufficiency (post-mortem examination showed cor pulmonale). One 49-year-old man died with bronchopneumonia of the remaining lung and diffuse bleeding in the space, one week after an extrapleural pueumonectomy with osteoplastic thoracoplasty. No source of the bleeding was detected at the post-mortem examination.

Six patients died from infection between twelve days and seven months after the operation:

Two patients died from tuberculous pericarditis, both on the twelfth day after operation. Therefore a special effort is made during resection for tuberculosis to avoid opening the pericardium.

Three patients died from empyema with a bronchial fistula. A 50-year-old man developed a staphylococcus chest wall infection with empyema and bronchial fistula and died after three weeks. The other 2 patients died after five weeks and seven months with a tuberculous empyema and bronchial fistula. Attempts to close the bronchial fistula after reamputation and adding an extensive resection of the chest wall have been of no help in patients with bronchial fistula due to tuberculous infection.

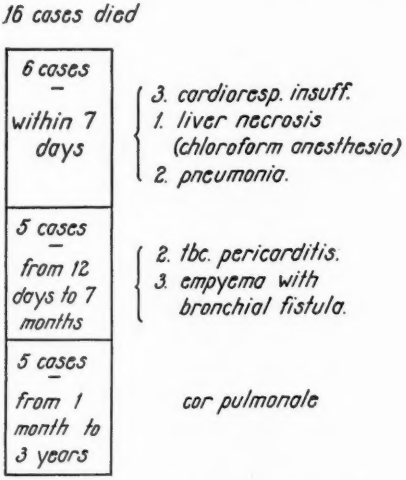
16 cases died
6 cases — within 7 days
3. cardiaresp. insuff.
1. liver necrosis (chloroform anesthesia)
2. pneumonia.
5 cases — from 12 days to 7 months
2. tbc. pericarditis.
3. empyema with bronchial fistula.
5 cases — from 1 month to 3 years
cor pulmonale

Fig. 5.—Five patients have died from cor pulmonale. This number is expected to increase with time.

One 34-year-old woman died three months after a left-sided pneumonectomy and two days after an upper lobectomy on the right side with a simultaneous osteoplastic thoracoplasty. She vomited and developed an aspiration pneumonia in the right lower lobe. In these patients with an extremely low respiratory reserve, a tracheostomy is now performed at the end of the operation. Then an ordinary tracheostomy cannula, provided with a rubber cuff, is used for artificial ventilation when indicated. This rubber cuff will also prevent aspiration. As there is very little tidal volume, it will otherwise be difficult for the patient to expectorate the aspirated material.

Five patients died from ventilatory insufficiency and cor pulmonale one month to three years after the operation.

Other Complications.—

Three patients had a primary tracheostomy and prolonged artificial ventilation for 3, 10, and 12 days due to ventilatory insufficiency.

Two patients had the same treatment due to postoperative infiltration in the only remaining lung. This infiltration had disappeared after seven to ten days with antimicrobial and respirator treatment.

Four patients developed pulmonary edema, 2 of whom had to have a tracheostomy.

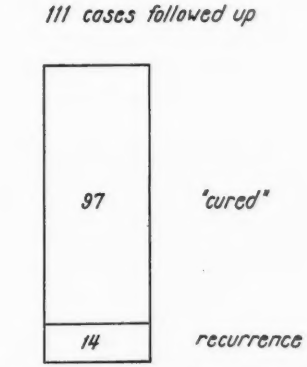

Fig. 6.—Ninty-seven patients of 111 were considered "cured."

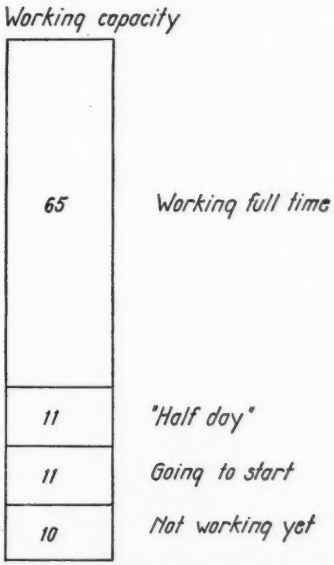

Fig. 7.—Working capacity.

One patient developed a tuberculous pericarditis after a lesion of the pericardium during the resection. The pericardium was aspirated and now four years after operation there is no sign of constrictive pericarditis.

Three patients needed revision thoracoplasty due to chest wall infection; this operation consisted of a wide excision of the chest wall leaving only skin on the mediastinum.

Seventeen patients had to have sutures removed from the bronchial stump before chromic catgut was used as suture material for the bronchus; stainless steel sutures have been removed as long as four years after the operation.

"Cured Patients."—

The aim of the surgical treatment for pulmonary tuberculosis is to make the patient free from tubercle bacilli in the sputum. Therefore, a patient is considered as "cured" if at the one-year follow-up the guinea pig test on sputum and gastric washing, as well as the culture and the direct smear of sputum, is

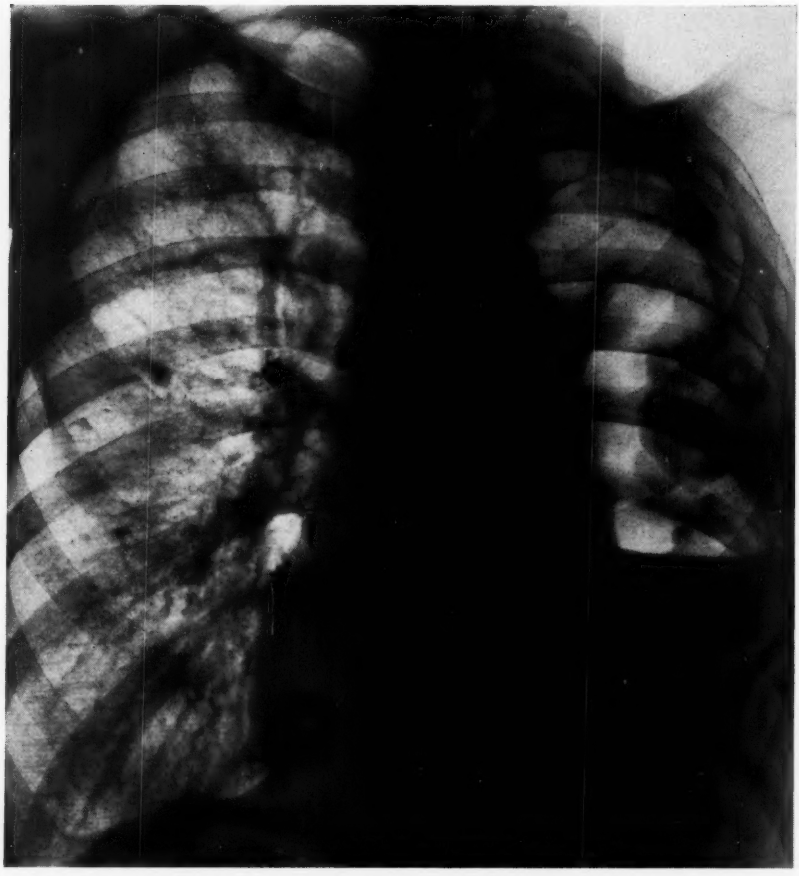

Fig. 8A.—An x-ray taken of a 37-year-old man with a left-sided tuberculous empyema, bronchopleural fistula, and a destroyed lung. Maximal breathing capacity 19 L./min.

negative on three consecutive days and no active disease is found on the x-ray investigation. All these criteria were fulfilled in 91 of the "cured" patients. In the remaining 6 patients, it was not possible to obtain sputum and therefore only the guinea pig test on the gastric washing was performed and found nega-

tive, thus 87 per cent of the 111 patients followed up are considered to be "cured." Some patients have been followed for five years but in the majority only the one-year follow-up is reported (Fig. 6).

Working capacity: Of the "cured" patients, 25 men and 39 women (65 per cent) were working full time. Four men and 6 women (11 per cent) were doing a half day's work. Eleven men and 12 women had not yet started work one year after the operation, but, of them, 5 men and 7 women were going to take up work again in the near future. Housework and office work was most often represented, but a nurse, an officer, a driver, and a bricklayer performed full-time work one year after operation (Fig. 7).

Fig. 8*B*.—An x-ray made one year after operation. The maximal breathing capacity is 18 L./min. The guinea pig test is negative on sputum and gastric washings.

The arm movements: The arm movements were normal in 42 (48 per cent) patients. In the remaining patients there was an impaired ability to bring the arm on the operated side straight up in the air (i.e., 180 degrees). Twenty-one

patients could bring the arm on the operated side up to 170 degrees, 14 patients up to 160 degrees, 11 patients up to 150 degrees, and 5 patients less than 140 degrees.

Pain: In 78 patients (80 per cent), there was no pain connected with maximal arm movements. Eighteen patients complained of some discomfort which in most cases was due to the scapula riding over some prominent rib or rib regeneration. In some patients pain was felt over the lowermost ribs on the side operated upon.

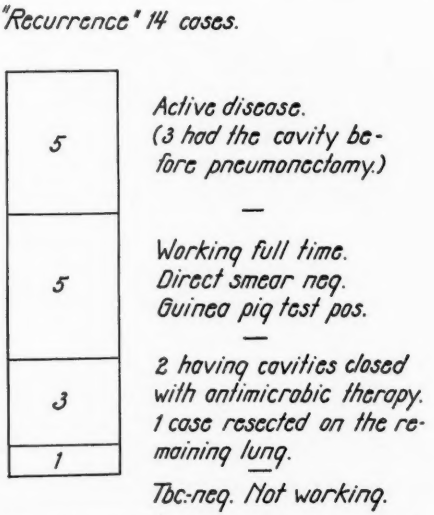

Fig. 9.—Fourteen patients were not "cured."

Cough: Sixty-eight patients (70 per cent) were free from cough but 29 had an irritating cough, mostly in the mornings. Seventeen of these patients with a long-standing irritating cough were found to have suture granulomas and the cough disappeared in most of these patients after removal of sutures through the bronchoscope. Many of these 29 patients reported that they had coughed up silk stitches on several occasions.

Dyspnea: Sixty-three patients (69 per cent) were free from dyspnea in their usual activities but 30 patients complained that they were short of breath. The postoperative values for the maximal breathing capacity are shown in Table II. The lowest value was 18 L./min. in a 37-year-old man having gone through a left extrapleural pneumonectomy (Figs. 8*A* and 8*B*). This man could

TABLE II. THE POSTOPERATIVE VALUES OF MAXIMAL BREATHING CAPACITY (MBC) IN LITERS PER MINUTE

MBC	MEN	WOMEN
10-29	2	8
30-49	8	24
50-69	14	20
70-89	11	2
90-109	4	-

walk slowly for 30 meters and was then very short of breath. His arterial oxygen tension was 59 mm. Hg; the carbon dioxide tension 58 mm. Hg; and the pulmonary artery pressure 35/15; mean 25 mm. Hg at rest; and 71/72; mean 49 mm. Hg during exercise (75 Kgm./min.). He was, however, sputum free and the guinea pig test was negative but he did not perform any work.

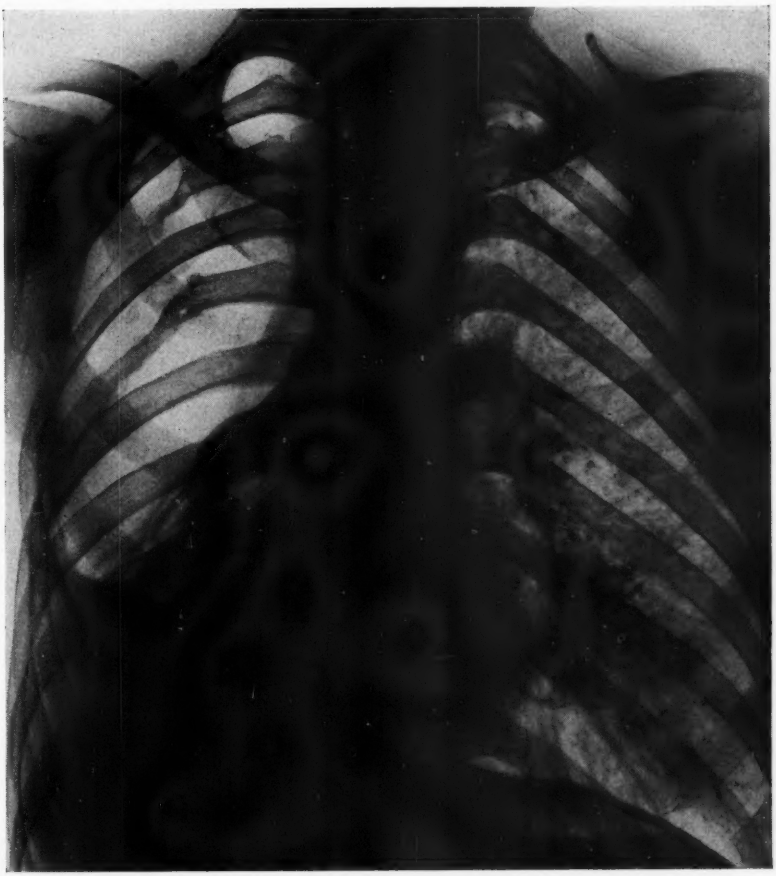

Fig. 10A.—An x-ray taken of a 29-year-old man with a cavity under a three-year-old right-sided extrapleural pneumothorax. There is, as well, a cavity in the apex of the left lung.

The following correlation has been found between the maximal breathing capacity and the patient's own feeling of shortness of breath. Even after a total thoracoplasty, only one-third of the patients had the mediastinum in the midline. In two-thirds of the patients, the x-ray examination showed a dislocation of the mediastinum to the operated side with a correspondent overdistention of the remaining lung.

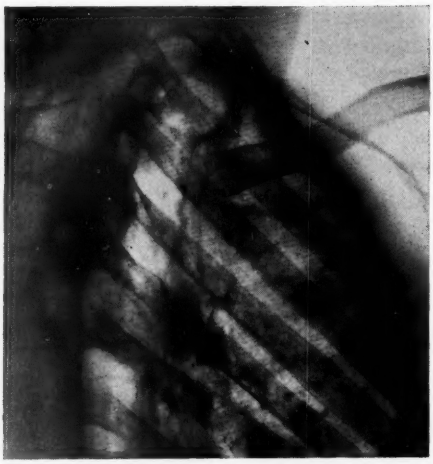

Fig. 10*B*.—This x-ray demonstrates the cavity in the left upper lobe.

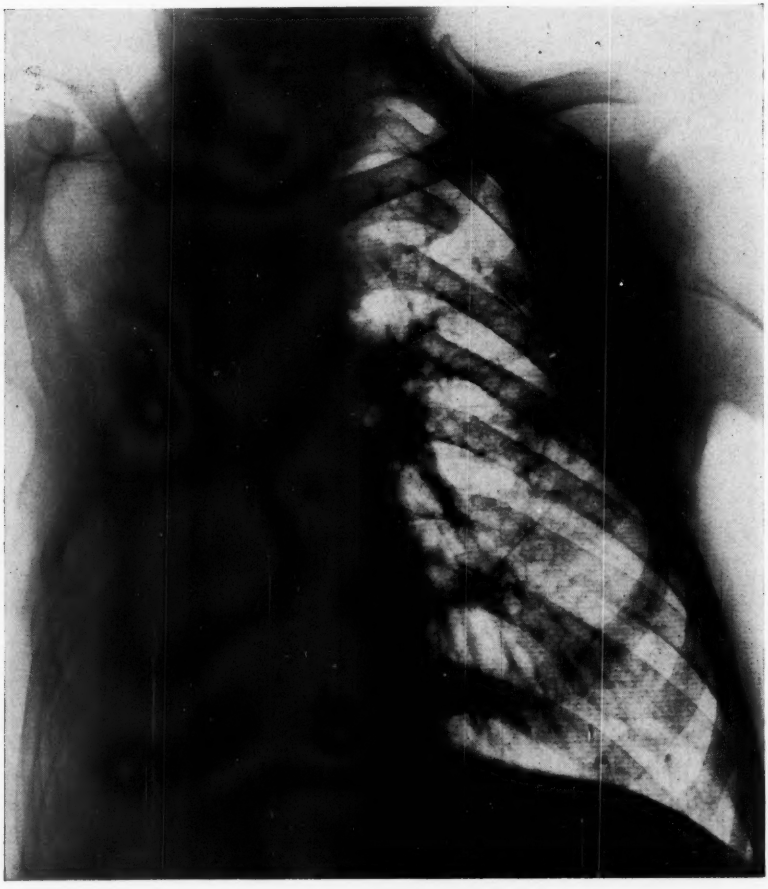

Fig. 10*C*.—An x-ray taken after resection of the right lung (March, 1954) and the apicoposterior and inferior lingula segments of the left upper lobe (March, 1955). Prolonged artificial ventilation was used during the last postoperative course.

TABLE III. THE CORRELATION BETWEEN THE PATIENT'S SUBJECTIVE FEELING OF SHORTNESS OF BREATH AFTER A PNEUMONECTOMY AND FOUND VALUE OF THE MAXIMAL BREATHING CAPACITY (MBC)

	MBC (L./MIN.)	
	MEAN VALUE	RANGE
24 men not feeling short of breath	66.8	96-32
9 men feeling short of breath	48.8	80-18
25 women not feeling short of breath	51.5	78-40
19 women feeling short of breath	36.5	58-20

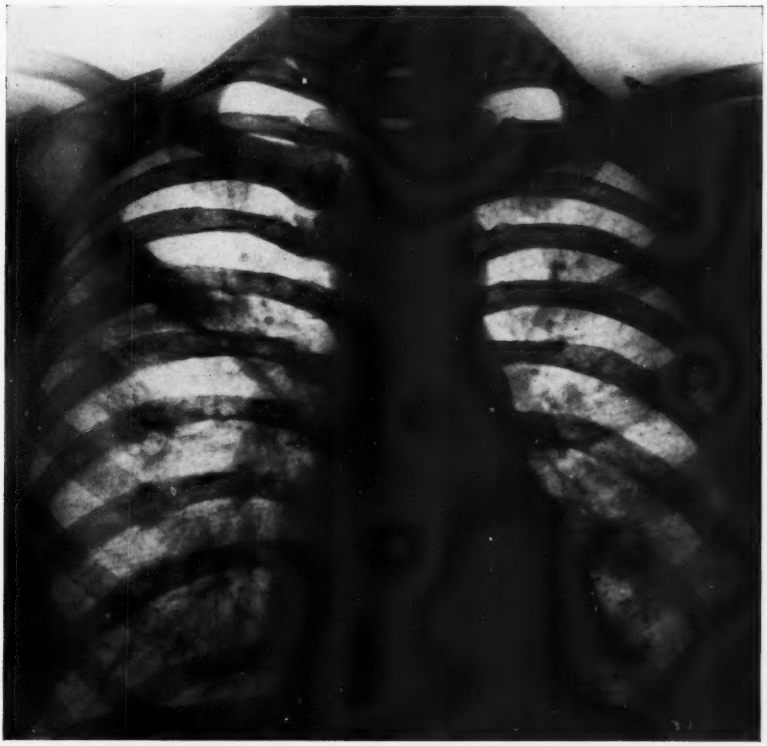

Fig. 11A.—An x-ray of a 22-year-old woman which shows an infiltration with a central cavity in the right upper lobe (1947).

Not "Cured" Patients.—

Fourteen patients were not "cured" by a pneumonectomy (Fig. 9).

Four of these patients had activity in the remaining lung (3 with cavities), none of them were working. The 3 patients with cavities in the only remaining lung had had these cavities at the time of operation.

Five patients had a positive guinea pig test but a negative direct smear and were working full time.

Three patients with bilateral disease had a cavity in the only remaining lung one year after the pneumonectomy. In 2 of these, there was a very good

response to chemotherapy with "closure" of the cavity and the patients were able to return to work. The third case, a 29-year-old man, underwent a right extrapleural pneumonectomy and a 10-rib thoracoplasty. One year later, the apicoposterior and inferior lingula segments of the left upper lobe were resected for a tuberculous cavity. After that operation the patient is in a very good condition, his sputum is negative, and he is going to take up office work. His maximal breathing capacity eight months after the last operation is 59 L./min. (Figs. 10*A*, *B*, *C*).

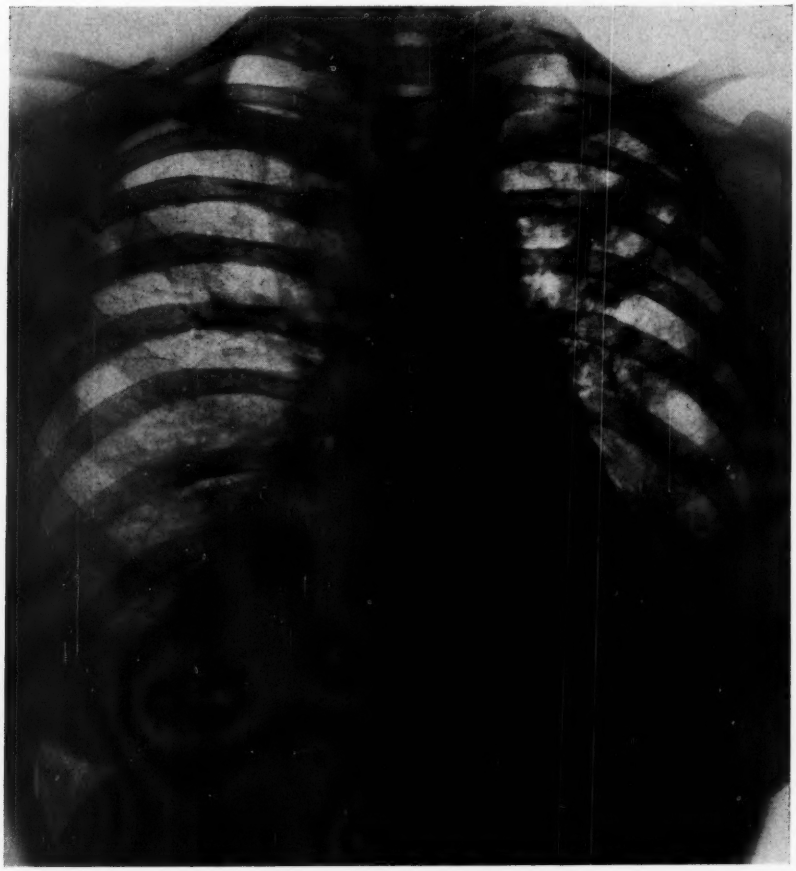

Fig. 11*B*.—After 5 years' right-sided pneumothorax, there was still a cavity in the right upper lobe. On the left side, several cavities necessitated pneumonectomy.

One patient has had ulceration of the main bronchus to the remaining lung with positive sputum three years after pneumonectomy but has reacted well to antimicrobic therapy.

One patient is sputum negative but is very nervous and now, five years after the pneumonectomy, has not yet taken up any work. Her weight is 35 kilograms.

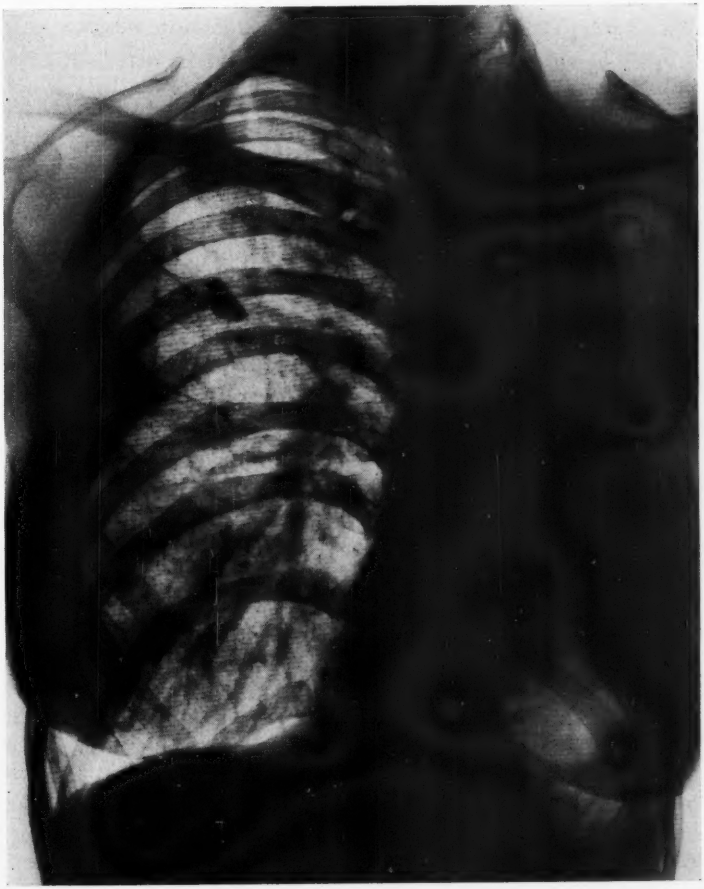

Fig. 11*C*.—An x-ray taken 3 years after the left pneumonectomy. The cavity in the right upper lobe is inspissated and calcified.

THE CONTRALATERAL LUNG AFTER A PNEUMONECTOMY FOR PULMONARY TUBERCULOSIS

It is a general impression that the contralateral lung has withstood the pneumonectomy very well. One 22-year-old woman had a cavity under a five-year-old pneumothorax on the right side when left pneumonectomy and, later, a 10-rib thoracoplasty were performed in two stages. One year after the pneumonectomy, the cavity in the lung was inspissated and calcified and the pneumothorax abandoned (Figs. 11*A*, *B*, *C*). The guinea pig test on sputum and gastric washing was negative and she started to work. Three years after

the operation, the tests are still negative, and she is in a very good condition, working full time, newly married, can climb 4 flights of stairs, and has a maximal breathing capacity of 48 L./min. Reactivations, even with cavitation, have reacted well to chemotherapy. Table IV will indicate the condition of the contralateral lung at the time of operation and the result ("cure"-guinea pig test on sputum and gastric washing negative with no active disease at the x-ray investigation).

TABLE IV. THE CONDITION OF THE CONTRALATERAL LUNG AT THE TIME OF OPERATION CORRELATED TO THE RESULT AT THE FOLLOW-UP

CONDITION OF THE CONTRALATERAL LUNG	"CURE"	RECURRENCE
Normal	47	4
Small infiltration	37	5
Infiltration earlier treated by pneumothorax	4	-
Cavity "closed" by conservative treatment	2	-
Cavity "closed" by pneumothorax	3	2
Open cavity	2	3
Open cavity remaining after pneumothorax treatment	1	-
Open cavity under a pneumothorax	1	-
Total	97	14

On the other hand, 14 of the 16 patients that died had had significant tuberculosis, in 6 cases with cavitation on the contralateral lung. The general experience from resections on patients with bilateral tuberculosis has shown that patients with a pneumothorax on the contralateral lung often have difficulties during the postoperative period. The respiratory work for the patient with an old pneumothorax on the contralateral lung is considerably increased. It may be possible for the patient to perform an efficient ventilation and to bring up the secretion for a few days after the operation. Then, the patient is exhausted from the increased respiratory work and the ventilation becomes more and more insufficient with carbon dioxide retention. The immediate risk is therefore considerably higher when the patient has had a pneumothorax on the contralateral lung. The patient may tolerate very well the occlusion of the pulmonary artery on the side to be operated upon for some time. Yet, the respiratory work with expectoration performed with an old pneumothorax lung, will often be too much for the patient after a few days. This is often reported as cardiorespiratory insufficiency in the reports. The death in such cases is often due to carbon dioxide retention. Therefore a resection, especially a pneumonectomy, should not be performed on such patients unless it is possible to take over the patient's respiration with prolonged artificial ventilation during the postoperative period.

The long-term prognosis is also considerably worse in patients having had pneumothorax on the only remaining lung. Two such patients have already died from cor pulmonale after six months and three years, respectively.

SUMMARY

Pneumonectomy is reserved for destroyed lungs whether a bronchial stenosis is present or not. A one-stage procedure with resection and osteoplastic wall thoracoplasty is recommended. If the function of the remaining lung is

impaired by disease or an old pneumothorax, the respiratory work for the patient in the postoperative period is often too great, with carbon dioxide retention as the result. Then prolonged artificial ventilation through a tracheostomy is indicated until the patient has regained strength enough to perform adequate ventilation and bring up the secretion. Of 111 cases followed 1 to 5 years after operation, 97 patients or 87 per cent are considered "cured." Of the 14 patients with recurrence, 5 are well and working with negative sputum but with a positive guinea pig test on the gastric washing.

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HEMORRHAGE FROM FIBRINOLYSIS IN PULMONARY SURGERY

Report of a Case With Study of Coagulation Mechanism

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THOUGH the hazard is now well known, the exact nature and pathogenesis, and hence the best treatment, of the coagulation defects that may develop in the course of operations on the lung are still poorly understood and may not be the same in every case. The present report describes a fatal case in which the clotting defect was studied in some detail.

CASE REPORT

The patient, a 43-year-old Caucasian paper-cutter, was admitted to the Massachusetts Memorial Hospitals on Oct. 15, 1954, complaining of shortness of breath and swelling of the ankles. For approximately one year he had noted a nonproductive cough which he attributed to "bronchitis." Four months before admission he experienced, for the first time, slight dyspnea which became increasingly severe, and ankle edema. He was treated with digitalis and mercurial diuretics with gradual diminution of dyspnea and edema but the cough persisted.

On *physical examination,* the patient was a slender middle-aged man who appeared chronically ill but was in no acute distress. Temperature was 100° F., pulse 100 per minute, respirations 20 per minute, and blood pressure 126/76 mm. Hg. Neck veins were not distended. The trachea appeared to be slightly deviated to the right. Examination of the lungs showed dullness over the right lower lung field anteriorly and posteriorly, above which there were moist râles and diminished breath sounds. The left lung was hyperresonant but free of râles. The heart was not clinically enlarged. There were occasional ventricular extrasystoles. A high-pitched apical presystolic murmur was present. The liver and spleen were not palpable and there was no peripheral edema. Neurological examination was unremarkable.

Laboratory data were as follows: blood urea nitrogen, 15 mg. per cent; fasting blood sugar, 77 mg. per cent; CO_2-combining power, 30.6 meq./L.; chlorides, 98 meq./L.; sodium, 135 meq./L.; and potassium, 5.5 meq./L. Erythrocyte sedimentation rate was 28 mm. in one hour. The hemoglobin was 12.9 Gm. per cent and the hematocrit 40 per cent. The number of leukocytes ranged from 7,800/mm.^{3} to 9,500/mm.^{3}, with essentially normal differential counts. The sputum examination was unremarkable. Circulation time (arm to tongue) was 12 seconds. Venous pressure was 4.5 cm. of saline at rest, 7 cm. during exercise, and 5.5 cm. 2 minutes after exercise. First strength PPD (purified protein derivative) skin test was negative. An electrocardiogram was within normal limits. The laminograms of the chest done on Oct. 18, 1954, showed areas of loculated fluid on the right side. There was a suggestion of a mass at the right hilus, with narrowing of the intermediate and lower lobe bronchi, interpreted as suspicious of tumor. Bronchoscopy demonstrated no abnormalities except for mucosal erythema of the right middle and lower lobe bronchi. Cytologic study of the bronchial aspirate was negative for tumor cells. Thoracentesis was performed on two occasions in October, 1954, with recovery of a total of 700 ml. of serosanguineous fluid, pathologic study of which yielded no evidence of tumor cells. Fluoroscopy of the chest

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revealed minimal excursion of the right hemidiaphragm with no paradoxical motion. Right prescalene lymph node biopsy demonstrated "chronic inflammatory changes" only. The coagulation mechanism was not studied preoperatively, as nothing in his history suggested a hemostatic defect.

Although no tissue diagnosis of malignancy had been possible, the presence of hemorrhagic pleural effusion, together with the laminographic findings suggesting neoplasm, were felt to warrant exploratory thoracotomy, which was performed on Nov. 4, 1954, under general endotracheal anesthesia. Extrapleural dissection was required initially because of the markedly thickened and adherent pleura. A dense fibrous and fibrinous cortex covered both visceral and parietal surfaces. The lung parenchyma appeared unremarkable on cursory palpation and frozen section study of a pleural biopsy showed no evidence of tumor or tuberculosis. A small amount of hemorrhagic pleural fluid was present. In order to examine the lung satisfactorily, as well as to remove the ventilatory restriction secondary to the fibrothorax, visceral and parietal pleural decortication was performed. This proved to be technically difficult and was attended with marked blood loss. However, there was no generalized bleeding. Blood repletion appeared adequate, the patient receiving 2,000 ml. of whole blood during the procedure.

Before the thoracotomy wound was closed, it was noted that the pleural cavity was free of blood clot; no significance was attached to this fact at the time, however. A slow, generalized ooze of blood was seen from all sites of decortication, but did not appear out of proportion to the extent and type of operation.

At the conclusion of the three-hour procedure and after the wound had been completely closed, the blood pressure, previously stable, suddenly became unobtainable. Alarming bleeding was observed from the thoracotomy tubes. Resuscitative measures included the liberal use of whole blood transfusions which were ineffective in raising the blood pressure. The pulse remained relatively slow and forceful. L-norepinephrine was unsuccessful in improving the hypotension. Preparations were made to reopen the chest with the possibility of ligating one or more actively bleeding vessels. However, hematological consultation had been secured at the time of onset of hemorrhage and hastily completed preliminary studies indicated the presence of a coagulation defect, due to fibrinolysis. It was therefore felt that exploratory thoracotomy would be futile. Multiple transfusions with whole blood were continued. The sanguineous drainage in the thoracotomy water-seal bottle showed no tendency to clot and it was observed that unusual oozing occurred from the skin at sites of venipuncture. One unit of plasma and 4 Gm. of fibrinogen were administered intravenously without appreciable effect on the bleeding. Resuscitative measures were continued, including artificial respiration and massive transfusion of whole blood, but all efforts to maintain the patient were unsuccessful and he died four hours after the hemorrhagic tendency first became manifest. The total amount of whole blood administered following the clinical onset of the clotting defect was 5,500 c.c.

Autopsy was performed four hours post mortem. There were hematomas and ecchymoses of the skin. No blood clot was encountered at any point in the vascular system and the heart blood was completely fluid. No blood clot was seen at any site in the fresh thoracotomy wound. The right pleural cavity contained 800 c.c. of dark red, unclotted blood. The right lung showed atelectasis, most pronounced in the middle lobe. The left lung was unremarkable. Examination of the heart showed rheumatic mitral stenosis. There was massive emphysema of the mediastinum and retroperitoneum, with dissection of the air between the leaves of the mesocolon. This was undoubtedly secondary to the decortication, which had been particularly difficult in the region of the diaphragm. Complete gross and microscopic study disclosed no evidence of carcinoma or tuberculosis.

COAGULATION STUDIES

Clotting tests done on a sample of venous blood taken about three hours before death gave the following results. The whole blood clotting time (Lee and White) in two glass tubes was 3½ and 4 minutes, thereby excluding the presence of a circulating anticoagulant. Good clots formed in both tubes but dis-

appeared completely within 20 minutes' incubation at 37° C. A clot from the same volume (1 ml.) of normal blood, washed in normal saline and suspended in about 0.8 ml. of the patient's serum, was apparently intact at 6 hours at 37° C., but was completely lysed within 24 hours.

The one-stage "prothrombin" test of Quick (using 0.1 ml. each of acetone-dried human brain extract, test citrated plasma, and $\frac{M}{40}$ $CaCl_2$) showed a prolonged clotting time (Table I). The addition to the patient's plasma of normal

TABLE I. DIAGNOSTIC ONE-STAGE "PROTHROMBIN" TIMES WITH PRESUMPTIVE EVIDENCE OF SPCA DEFICIENCY IN PATIENT'S PLASMA

ONE-STAGE "PROTHROMBIN" TIMES (SECS.)				
NORMAL PLASMA	PATIENT'S PLASMA	PATIENT + 10% NORMAL PLASMA	PATIENT + 10% NORMAL Al $(OH)_3$ PLASMA	PATIENT'S PLASMA + 10% OLD NORMAL SERUM
14	23	19	23	17

plasma treated with $Al(OH)_3$ (which contains Ac-globulin but lacks SPCA* and prothrombin) in a proportion of 1:10 had no effect on this clotting time, whereas the admixture of aged normal serum (rich in SPCA but lacking the other factors to which this test is sensitive) shortened it significantly. This suggests that the patient's plasma was deficient in SPCA precursor (factor VII, proconvertin). Prothrombin itself, estimated by the two-stage area method of Biggs and Douglas,[1] was 70 per cent, which is at the lower limit of normal.

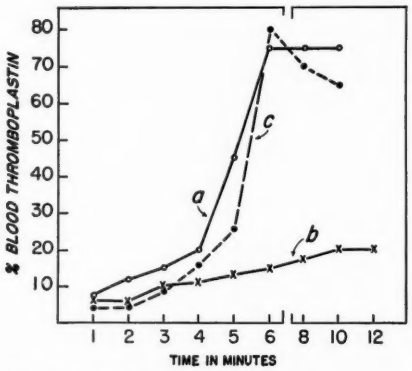

Fig. 1.—Intrinsic blood thromboplastin generated in mixtures of normal platelet suspension with (*a*) normal $Al(OH)_3$-treated plasma and normal serum; (*b*) normal serum and patient's $Al(OH)_3$-treated plasma; (*c*) normal $Al(OH)_3$-treated plasma and patient's serum. (100 per cent represents clotting time in substrate plasma of 10 seconds.)

The blood thromboplastin generation test[2, 3] showed that a potent thromboplastin was generated from a mixture of the patient's serum with normal platelet suspension and normal plasma treated with $Al(OH)_3$, i.e., the patient's serum, in spite of its deficiency in SPCA, had an adequate content of blood thromboplastin components (Fig. 1). On the other hand, when the generating mixture consisted of normal platelet suspension, normal serum, and patient's plasma treated with $Al(OH)_3$, the generation of thromboplastin was significantly impaired. The blood thromboplastin components present in $Al(OH)_3$

*Serum prothrombin conversion accelerator.

treated plasma are Ac-globulin (factor V, proaccelerin) and antihemophilic globin (thromboplastinogen); since no lack of Ac-globulin could be demonstrated (Table I), it follows that the patient's plasma had less than a normal content of antihemophilic globulin.

Using a modification of Schneider's rapid method for estimating fibrinogen,[4] the fibrin titer of the patient's plasma was 200, not significantly different from the normal plasma titer of 400. By the method of Ratsoff and Menzie, the patient's venous blood contained 194 mg. of fibrinogen per 100 ml., compared with 202 mg. per 100 ml. in normal control blood.

Blood drawn from the pleural cavity, before fibrinogen was given intravenously, did not clot and contained less than 10 mg. of fibrinogen per 100 ml. After the intravenous administration of 4 Gm. of Fraction I of Cohn, the blood from the pleural cavity, still fluid, contained 24 mg. of fibrinogen per 100 ml. Blood from the right atrium, taken four hours after death, was fluid and contained no fibrinogen. Like the pleural blood, it was totally lacking in both Ac-globulin and SPCA, but contained a near-normal amount of prothrombin as estimated by the two-stage area method.

The fibrinolytic activity in the pleural and post-mortem blood was further studied by observing its effect on a standard fibrin clot in the following manner. Solutions of fibrinogen (Fraction I) 0.15 per cent in 0.4 ml. quantities were mixed with 0.8 ml. of 0.85 per cent NaCl buffered with veronal acetate buffer at pH 7.4 which contained various dilutions of the patient's sera and normal serum to give the final concentrations shown in Table II. The resulting

TABLE II. LYSIS TIMES FOR STANDARD CLOTS FORMED BY ADDING 0.1 ML. THROMBIN TOPICAL (20 AND 500 UNITS PER ML.) TO 0.05% FIBRINOGEN IN BUFFERED (pH = 7.4) SOLUTION CONTAINING VARIOUS DILUTIONS OF PATIENT'S SERA OR NORMAL SERUM

DILUTION OF SERUM	UNITS OF THROMBIN USED (0.1 ML.)	TIME (MIN.) FOR COMPLETE LYSIS		
		ANTE-MORTEM PLEURAL SERUM	POST-MORTEM HEART SERUM	NORMAL SERUM
1/8	2	180	30	no lysis
	50	120	30	no lysis
1/16	2	180	60	no lysis
	50	120	20	no lysis
1/32	2	180	60	no lysis
	50	30	10	no lysis
1/64	2	300	60	no lysis
	50	20	10	no lysis
1/128	2	360	180	no lysis
	50	10	10	1,440
1/256	2	480	300	no lysis
	50	10	10	960
Saline only	2	no lysis	–	
	50	420	–	

0.05 per cent solutions of fibrinogen were clotted by the addition of 0.1 ml. of topical thrombin solution (Parke Davis Co.) prepared in two concentrations: 20 and 500 units per milliliter. (Two concentrations of thrombin were used because thrombin topical itself, in higher concentrations only, is strongly fibrinolytic, and this fibrinolytic action is inhibited by normal serum even in in high dilution. It therefore seemed desirable to observe the behavior of the

patient's sera toward a standard clot formed by such an excessive thrombin concentration as well as toward one formed by a low but adequate thrombin concentration.) Good and uniform clots formed in every tube, and were observed at frequent intervals for lysis. The time taken for complete disappearance of the clot was recorded (Table II). The serum taken from the pleural cavity before death, as well as that from the right atrium at autopsy, contained a potent fibrinolysin. This was especially pronounced in the post-mortem sample. When the standard clot was made with the lower thrombin concentration, lysis was less rapid in the samples containing the lower concentrations of serum, suggesting that the lytic activity was weakened by dilution in the absence of an adequate antifibrinolysin. However, in the samples cloted by an excess quantity of thrombin, the shortening lysis-time as the serum was progressively diluted demonstrated that the patient's blood did continue to exert some activity against the fibrinolytic action of thrombin topical. At the highest dilutions of serum in this series the lysis-times were the shortest recorded, presumably because of a synergistic lytic effect. It is of interest that these lysis-times (10 minutes) resemble the spontaneous lysis-time of the patient's own clot.

To determine whether the patient's serum was active against fibrinogen as well as fibrin, 0.4 ml. samples each of ante-mortem pleural serum and post-mortem heart serum were mixed with 0.4 ml. of 0.15 per cent fibrinogen solution. It had been intended to test at intervals for residual fibrinogen, but after periods varying from 15 to 23 minutes solid clots formed spontaneously in every tube. Presumably this coagulation was due to persistent thrombin, although it may have been mediated by the fibrinolytic factor itself, since chloroform-treated plasma may have this property.[5] On standing, total lysis of these clots occurred in the post-mortem samples in about 1 hour, and in the ante-mortem samples in 6 to 8 hours. This test was therefore inconclusive. Positive evidence of fibrinogenolysis, using this technique, was subsequently obtained with more dilute samples of the post-mortem serum. The platelets were not studied.

DISCUSSION

Although fibrinolytic activity of varying degree has been found in the blood in many clinical states, its mechanism and significance remain uncertain. The best general review is still that of Macfarlane and Biggs,[6] while Scott and coworkers[7] describe the practical problems of diagnosis and treatment in those surgical cases where it is of clinical importance. Severe bleeding has been ascribed to fibrinolysis in a variety of surgical situations involving shock,[7, 8] but most frequently in operations on the lung.[9-12] In most instances, these patients showed severe fibrinogenopenia, assumed to be due to fibrinolysis. In some cases, however, the evidence for this has not been adequate to exclude a possible alternative cause of fibrinogen depletion, namely, the systemic release of tissue thromboplastin from the operative site causing intravascular fibrin formation and loss, by consumption, of fibrinogen and other clotting factors from the circulating blood. In such circumstances the presence of fibrinolysis, unless it were striking (as in the present case), might well be incidental or secondary since it has been found, without obvious pathologic significance, in many different clinical and experimental conditions.[13-17] The hemorrhagic states with fibrinogenopenia that may occur in abruptio placentae are considered, with good

evidence, to be due to thromboplastin release,[18-21] although here also fibrinolysis has been described,[18, 22-25] playing an uncertain and probably variable role. The lung, like the placenta, is a rich source of tissue thromboplastin, and such a mechanism may well be operative in some cases of fibrinogenopenia occurring in the course of thoracic surgery, whether or not excessive proteolytic activity is found in the plasma.

The present case, however, like one patient of Coon and Hodgson[8] and one of Scott,[7] had a normal plasma fibrinogen level in spite of very rapid lysis of the fibrin clot once formed. Any depletion of fibrinogen, if it occurred, must have been slight and restored by transfusion. No clots were found post mortem, and none formed in the blood taken from the pleural cavity before death. Presumably, therefore, adequate clots had formed, but had been lysed before they were hemostatically effective. As with thromboplastin, the source of the fibrinolytic factor or its activator may have been the lung tissue itself.[6, 26] No evidence was obtained that the lysin circulating before death was active against fibrinogen.

The cause of the prolonged one-stage "prothrombin" time, apparently indicating SPCA deficiency, and of the deficiency in antihemophilic globulin, can only be surmised. These clotting factors may have been susceptible to the proteolytic enzyme that destroyed fibrin, but it is remarkable that none of the other factors was similarly reduced. There is no reason to suppose, in view of the negative history and the fact one brother examined had no clotting defect, that the patient was even a mild hemophiliac, though this possibility cannot be disproved. Experimentally, local tissue injury and thrombosis can cause isolated depletion of antihemophilic globulin,[28] presumably from excessive consumption, and intravenous injection of activated blood thromboplastin sometimes has the same result.[27] In this patient, much ineffective clotting must have taken place at the operative site, and antihemophilic globulin may have been consumed in excess of that contained in the transfused blood. Such a mechanism, however, would not explain the SPCA deficiency.

There was a striking difference between the time required for lysis of the patient's own clot (less than 20 minutes) and that necessary for lysis of a normal clot suspended in the patient's serum (more than 6 hours), a difference not due to plasma fibrinogen concentration. Evidently the lysin was much more active when present at the time of actual clot formation than when allowed to act on a preformed clot. A similar observation has been made in fibrinolysis due to excessive concentration of thrombin topical, the lysis being much more rapid when the excess thrombin is used to form the clot than when it is added immediately afterward.[27]

In the circumstances described here—rapid lysis of fibrin without significant depletion of fibrinogen—the administration of antifibrinolysin in the form of concentrated human albumin, as suggested by Scott and his colleagues,[7] may be more important than fibrinogen as a supplement to transfusion with whole blood, preferably fresh, which is always necessary. This emphasizes the importance of rapid diagnostic methods.[4, 7]

SUMMARY

The coagulation mechanism was studied in a patient dying of hemorrhage following pulmonary surgery and the findings are discussed with reference to

the literature. There was no fibrinogenopenia, but rapid lysis by the patient's serum of his own and standard fibrin clots was demonstrated. The plasma was deficient in antihemophilic globulin and SPCA precursor.

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Announcements

THE AMERICAN ASSOCIATION FOR THORACIC SURGERY

Notice of Annual Meeting

The Thirty-seventh Annual Meeting of The American Association for Thoracic Surgery will be held May 4, 6, and 7, 1957, in Chicago, Illinois. Headquarters will be at the Palmer House.

Requests for Hotel Reservations

These should be mailed directly to Mr. Edward Langford, Reservations Manager, Palmer House, Chicago. Please mention this Association, the type of accommodation desired, the date, and approximate hour of arrival and departure. If accommodations are desired elsewhere in Chicago, please communicate directly with the hotel of your choice.

Thoracic Surgery Forum

The Thoracic Surgery Forum will be continued as a special session at the 1957 meeting. The Forum is primarily for the presentation of short papers on current thoracic research, experimental problems, anatomical studies, and modified or new surgical techniques. The inclusion of any considerable amount of clinical material in these reports makes the choice more difficult and the Program Committee reserves the right to reject such papers, or to suggest their transferal to the Regular Program.

Papers at this session will be limited to ten minutes, including the showing of lantern slides or other illustrative material. At the discretion of the President, three minutes may be allowed as the maximum discussion for each paper.

All Thoracic Surgery Forum papers will be published together in one issue of the JOURNAL. Maximum length: 3000 words without illustrations. If illustrated, an appropriate number of words must be subtracted for each cut used.

Abstracts of Papers

Abstracts of all papers for presentation at the 1957 meeting must be received on or before Dec. 15, 1956, otherwise they will not be considered by the Program Committee.

Abstracts should be labeled "For Thoracic Surgery Forum," or "For Regular Program." The abstracts should contain from 200 to 250 words and accurately reflect the contents of the completed paper.

Five, repeat, five copies of *each* abstract must be sent to Miss Ada Hanvey, Administrative Assistant, The American Association for Thoracic Surgery, 600 South Kingshighway, St. Louis 10, Missouri.

Those on the program are reminded that papers presented at the meeting *must* be handed to the secretary immediately after their presentation. If they are not ready at that time there is a chance that they will not be published in THE JOURNAL OF THORACIC SURGERY.

Motion Picture Session

Provisions have been made to show a limited number of motion pictures to be selected on a competitive basis. *The films themselves,* together with descriptive material concerning length of presentation, etc., must be received by Dr. Karl P. Klassen, The Ohio State University, Columbus 10, Ohio, before Dec. 15, 1956.

It is planned to run the motion pictures in a smaller room at the same time as the scientific sessions. If the films are well labeled, it will not be necessary for the author to be present for comment.

Applications for Membership

Applications for Associate Membership in the Association must be received by the Membership Committee not later than Dec. 15, 1956, otherwise the application will be deferred for consideration until the 1958 meeting.

Applicants must be sponsored by three Active or Senior Members of the Association. In addition to the signatures on the application form, the sponsors will forward a *separate* letter concerning the applicant directly to:

Dr. O. T. Clagett
Chairman of the Membership Committee
Mayo Clinic
Rochester, Minn.

Sponsors are reminded that *new* letters of recommendation must be forwarded to the Membership Committee should their applicants be held over for reconsideration a second year. The new letters of recommendation should also be sent to Dr. Clagett, the Chairman of the Membership Committee.